STATE OF CALIFORNIA

The Resources Agency

Department of Water Resources

BULLETIN No. 118-1

EVALUATION OF GROUND WATER RESOURCES

SOUTH BAY

Appendix A: GEOLOGY

AUGUST 1967

RONALD REAGAN
Governor
State of California

WILLIAM R. GIANELLI
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FOREWORD

The South Bay Ground Water Basin in Alameda, Santa Clara, and San Mateo counties is one of the most intensively developed ground water basins in the State. Previous studies have indicated that the average withdrawal of fresh ground water exceeded the natural recharge for several years. The lowered ground water levels have resulted in extensive saline water intrusion and subsidence of the land surface. Local agencies are now artificially recharging the ground water basin in several areas using both local surface runoff and imported water, in an effort to stabilize water levels and prevent further intrusion and subsidence.

Previous investigations were limited in scope and treated in detail only a portion of the current area of investigation. The previous studies emphasized the ground water problems in each area, showed a need to study the ground water situation in the area as a whole, and revealed that more data on the area underlying San Francisco Bay and its adjacent tidelands must be collected and analyzed in order to evaluate the ground water resource in geologic and hydrologic terms.

The South Bay Ground Water Basin is of primary importance in the regulation and distribution of local and imported water supplies. Some segments of the basin have been rendered unusable and other segments are threatened by saline water intrusion. Further studies of the basin have been requested by agencies in Alameda and Santa Clara counties. The need for study of the entire ground water basin complex has been recognized by the Department for several years, and this need was accentuated by local plans for distribution of water from the South Bay Aqueduct. To obtain proper basin management and to maximize utility of the basin, the subsurface geologic and hydrologic conditions must be known, and plans must be developed for repelling or preventing saline water intrusion, subsidence of the land surface, and other problems relating to the management of the basin. Development of these plans must include the investigation, planning, and review of projects, physical structures and facilities for ground water protection and replenishment.

Bulletin 118-1, "Evaluation of Ground Water Resources, South Bay", will be published in two volumes: Volume 1, "Fremont Study Area" and Volume 2, "Santa Clara Study Area". This appendix presents the results of a detailed geologic study, which is the basis for both volumes of Bulletin 118-1.

William R. Gianelli

William R. Gianelli, Director
Department of Water Resources
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State of California

June 12, 1967

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ABSTRACT

This appendix describes the geology of the water-bearing sediments in the southern portion of the San Francisco Bay area, Alameda, Santa Clara and San Mateo counties, California. The information supports studies of the hydrology, water quality, and operational characteristics of the ground water basin.

Included is a brief description of the geologic history, which relates the succession of significant geologic events which formed the area of investigation. The physiography of the basin is briefly discussed. Landforms, or physiographic features, are the result of erosion and tectonic activity combined with transporting agents such as water, gravity, and wind acting over a long period of time on sediments comprising the surface of the basin. A detailed discussion of the physiography appears as Attachment 2.

The chapter on geologic formations and their water-bearing characteristics describes the sediments and rocks present in the basin and the aquifers and aquicludes that have been identified within these sediments. The lithology of the more permeable Recent and Pleistocene sediments is discussed. The older, underlying rocks, which are generally nonwater-bearing, are more briefly dealt with. Structural features in the basin and their relation to ground water movement is also discussed. The structural features include faults and the bedrock surface buried beneath the basin.

The various exploratory phases of this investigation are discussed in the chapter on geologic investigations. There are brief sections on the collection and analysis of basic data, geophysical surveys, test hole drilling, and installation of piezometers. A detailed discussion of the geophysical methods are contained in Attachment 3.

Finally, the physical and water-bearing characteristics of the three ground water areas and their respective subareas are discussed in detail. Discussion includes location of boundaries and description of the extent, thickness, lithology, and water-bearing character of aquifers and aquicludes within each subarea. Hydraulic inter-connection between different aquifers, zones where recharge to aquifers is possible and effects of structural features on movement of ground water through each of the ground water subareas is also discussed.

CHAPTER I. INTRODUCTION

The objective of this appendix is to present in detail the geologic conditions which affect the occurrence and movement of ground water in the South Bay Ground Water Basin.

The area of investigation, shown on Plate 1, includes portions of Alameda, Santa Clara, and San Mateo counties. The main ground water storage area is the North Santa Clara Valley, which extends from approximately the San Mateo Bridge, south to Coyote Narrows and is bounded by the mountainous area surrounding the valley. The valley area occupies the southern, and most important, portion of the North Santa Clara Valley Ground Water Basin and is referred to in this report as the South Bay Ground Water Basin. The basin is bounded on the west by the Santa Cruz Mountains and on the east by the Diablo Range. These two ranges converge at Coyote Narrows to form the southern limit of the basin.

The northern boundary of the study area, just north of the San Mateo Bridge, does not mark the northern limit of the ground water basin. However, this study limit was chosen for three reasons: essentially, it represents the northern limit of the depositional cone of Alameda Creek; it represents the northern limit of subsurface information beneath this portion of San Francisco Bay (test holes along the bridge alignment); and it coincides in San Mateo County with the area of shallow bedrock between Coyote Point and the western edge of the basin.

The southern boundary of North Santa Clara Valley, as used in this report, differs from that used in Bulletin No. 7, "Santa Clara Valley Investigation".[9] Bulletin No. 7 used the ground water divide near Morgan Hill as a boundary, while in this report the constriction in the valley and in depth of water-bearing deposits at the Coyote Narrows, one mile north of the community of Coyote, is used as the boundary.

Previous Investigations

Ground water has been and continues to be the largest single source of water for domestic, irrigation, and municipal uses in Alameda and Santa Clara Counties. Interest in this subsurface source of water has resulted in publication since 1915 of seven significant reports covering all or parts of the present study area. These seven reports, and other geologic reports covering the area, are listed in Attachment I, "Bibliography".

The first detailed study of the area was completed in 1915 by W. O. Clark and appeared as U.S. Geological Survey Water Supply Paper 345, entitled "Ground Water Resources in the Niles Cone and Adjacent Areas, California".[12] This report remained for many years as the most complete and accurate description of ground water conditions in that portion of Alameda County adjacent to San Francisco Bay.

The drastic lowering of ground water levels prior to the 1920's, a result of a heavy pumping draft, resulted in a report by Tibbetts and Kieffer in March 1921, entitled "Report to Santa Clara Valley Water Conservation Committee on Santa Clara Valley Water Conservation Project".[32] This report recommended the establishment of a Water Conservation District, the construction of dams and surface water conveyance facilities, and the extensive use of artificial recharge of ground water. The basic recommendations presented were adopted years later and the facilities constructed largely alleviated the pressing water needs and allowed the ground water levels, for a time, to recover.

In 1924, W. O. Clark again reported in detail on ground water conditions in U.S. Geological Survey Water Supply Paper 519, "Ground Water in South Santa Clara County, California".[11] Clark expanded his coverage to include all of the present study area together with that portion of Santa Clara Valley south of Coyote Narrows.

In 1933, the California Division of Water Resources, predecessor to the Department of Water Resources, in response to a request by the newly established Santa Clara Valley Water Conservation District, published Bulletin No. 42, entitled "Santa Clara Investigation".[5] This bulletin described the historic ground water level recession, the resulting amount of ground water depletion, and the quantity of replenishment from surface streams in the area.

The Division of Water Resources studied that portion of North Santa Clara Valley Ground Water Basin underlying Santa Clara County during the period 1948 to 1954. In that investigation, considerable knowledge of geologic conditions governing movement of ground water was obtained in both North and South Santa Clara Valleys, and the results were published in State Water Resources Board Bulletin No. 7, "Santa Clara Valley Investigation",[9] dated June 1955.

During the period 1948 to 1955, the California Division of Water Resources conducted a ground water investigation in Alameda County comparable to the earlier Santa Clara County Investigation, covering the area adjacent to San Francisco Bay and Livermore Valley. The results were presented in Bulletin No. 13, "Alameda County Investigation",[8/] published in November 1962.

From July 1957 to June 1958, the Department conducted further detailed studies of the extent and causes of saline water intrusion into the ground water of southern Alameda County. The results of that investigation were published as Bulletin No. 81, "Intrusion of Salt Water Into Ground Water Basins of Southern Alameda County",[6/] December 1960. Emphasis was placed upon the degree to which faulty and abandoned water wells were contributing to the intrusion problem. Geologic conditions were investigated in detail in areas where sea water intrusion was known to have occurred.

In 1962, the U.S. Geological Survey published Water Supply Paper 1619-C, "Subsidence in the Santa Clara Valley, California - A Progress Report".[25/] The history of land subsidence in the Santa Clara Valley was summarized in this brief paper and related subsidence to geology and ground water.

CHAPTER II. GEOLOGIC HISTORY

The oldest rocks exposed in the Diablo and Santa Cruz Ranges date back 160 million years to the Jurassic period, but because the history of these rocks has very little to do with the development of the South Bay Ground Water Basin, only the geologic history of the past 12 million years since the Pliocene epoch, is included in this appendix.

Pliocene History

In early Pliocene time, the landscape of the San Francisco Bay region was entirely different than it is today. Structural troughs were located east and northwest of a long, low range of mountains occupying what is today the bay depression. The western trough contained an arm of the sea in which marine sediments of the Purissima and Merced Formations gradually accumulated.

The land barrier between the troughs prevented an eastward migration of the sea and allowed for continental deposition in the eastern trough by the process of erosion of the land barrier. Erosion and deposition gradually reduced the entire landscape to one of low relief, and more than 5,000 feet of sediments progressively filled the two troughs.

The relative quiet of the early part of the Pliocene epoch came to an end about two million years ago, during late Pliocene time. The entire region between the sea and the Great Valley was subjected to compressional forces from the northeast and southwest. The flat-lying Pliocene sediments were intensely folded, faulted, and uplifted into a series of parallel northwest-southeast trending ridges and narrow valleys. Many of the major faults known today probably originated or were reactivated at this time.

The late Pliocene uplift elevated the entire Coast Ranges and the Pliocene sea gradually retreated to beyond the present coast-line, except for an embayment just south of the City of San Francisco. This embayment apparently remained stable for a considerable period of time. During this uplift and the erosion cycle that followed, the area occupied today by the Santa Clara Valley apparently remained a depressed area, probably controlled by a combination of downwarping and movement along the ancestral Hayward and San Andreas fault zones. While marine deposition continued in the embayment, alluvial sediments were being deposited as fans and outwash plains in the gradually subsiding Santa Clara Valley depression. These continental deposits are now called the Santa Clara Formation in the South Bay area, and the Alameda Formation in the North Bay area.

During late Pliocene time, the streams depositing the Santa Clara and Alameda Formations probably flowed westward through a narrow valley south of San Francisco to reach the ocean near Lake Merced, because the present drainage outlet through the Golden Gate had not yet been formed.

Pleistocene History

The erosion cycle that began with deformation and uplift near the end of the Pliocene epoch continued into early Pleistocene time. Erosion attacked the weak, newly folded sediments, quickly wore them down to the level of the more resistant ridges of older rocks, and filled in the valley depressions. As erosion continued, even the resistant ridges slowly were reduced until a gently-rolling landscape resulted. Because weak rocks were more prevalent south of San Francisco Bay, the early Pleistocene surface is more widely developed there and can be seen today in the southern portion of the Diablo Range in the form of well preserved, concordant summits.

Deposition of marine sediments continued south of San Francisco throughout Pliocene and early Pleistocene time. The sea gradually became more shallow until by the early part of the Pleistocene epoch, the embayment had become a series of brackish to fresh water lagoons.

As the early Pleistocene erosion cycle progressed, land barriers were gradually eroded, allowing the drainage from the Great Valley to find its way westward along its present course to the sea. An east-west trending downwarp, where Suisun and San Pablo Bays now lie, also may have been responsible for the route chosen by the ancestral Sacramento-San Joaquin Rivers.

The early Pleistocene erosion cycle produced a widespread late mature topography, largely developed on weak sediments and surmounted by more resistant masses preserving the earlier Pliocene erosion surface.

The gentle early Pleistocene landscape was changed in mid-Pleistocene time by renewed uplift and intensive faulting of the Coast Ranges. This mid-Pleistocene orogeny brought an end to marine deposition south of San Francisco. The continental Santa Clara Formation continued to be deposited on the flanks of the valley depression south of the present bay.

Major folds and faults originally formed in the Coast Ranges at the end of the Pliocene epoch were accentuated, new folds were developed in the Plio-Pleistocene portion of the Santa Clara Formation, and highland areas were re-elevated. The coastline took on the general shape it retains today. This episode of crustal deformation was not nearly as severe as the orogeny at the close of the Pliocene epoch.

Block faulting on a large scale took place near the present bay and generally shaped anew the bay depression. The Berkeley Hills block and the Diablo Range were uplifted along the Hayward fault, producing a spectacular west-facing scarp. The valley depression continued to receive continental deposits in its southern portion, but reactivated subsidence was initiated that would soon contribute to inundation of the northern portion by waters of San Francisco Bay. West of the bay depression, the Santa Cruz Mountains and the Montara block were elevated and the latter was tilted gently to the east. These mountains were elevated 1,500 to 2,500 feet in a series of intermittent movements marked by a number of remarkable wavecut terraces on the seaward slopes. The mountains east of the valley depression probably rose in a similar intermittent fashion. The elevation of all the mountain blocks was gradual enough so that the Sacramento-San Joaquin River system was able to maintain its established course to the sea. Vigorous Alameda Creek also maintained its course across the rising Berkeley Hills block, in spite of a watershed that did not yet include the large area tributary to Livermore Valley.

The Santa Clara Valley depression gradually subsided along the several parallel northwest-trending faults that now lie concealed beneath the valley alluvium between the Hayward and San Andreas fault zones. Not all of the fault blocks subsided uniformly, as shown by the central one, of which the Coyote Hills are a part, which now lies between two bedrock troughs. Tectonic subsidence also has not occurred uniformly along the axis of the valley. This is illustrated by a large area of bedrock, only about 600 feet below ground surface, which crosses the valley just north of Coyote Hills. This is in contrast to Plio-Pleistocene sediments more than 1,500 feet thick beneath the valley in the San Jose area.

The area of concealed bedrock north of Coyote Hills must have been severely eroded as it was rising, because Cretaceous and early Tertiary rocks appear to be missing there. In contrast, the thick section of sediments in the depression near San Jose suggests that deposition was continuous there. Streams draining the depression probably maintained their flow northward across the rising bedrock area along the trough just east of Coyote Hills or through narrow canyons not yet recognized in the bedrock surface.

The sharp features produced by the mid-Pleistocene deformation were quickly subdued by erosion and the landscape developed to a stage of early maturity. Within the valley, erosion attacked the Alameda and San Antonio Formations on the north and portions of the Santa Clara Formation on the south. This erosion probably produced a moderately rugged topography in the valley, which was characterized by hills and steep ravines formed by streams emerging from the surrounding highlands. The streams were generally at the same locations as they are today.

Weak crustal deformation occurred again in late Pleistocene time which essentially set the stage for features present in the Bay region today. The Berkeley Hills were slightly elevated, coastal terraces were warped, the Merced, San Antonio, and Santa Clara Formations were slightly deformed, and the bay depression again subsided.

The Pleistocene was an epoch of world-wide glaciation and large changes in sea level. During each of the four glacial stages, vast quantities of water were accumulated as continental ice sheets which lowered the sea level in excess of 300 feet. During the interglacial stages, the melting ice sheets raised the sea level about 100 feet higher than it is today. The glacial and interglacial stages are shown in Table 1.

Table 1

TIMETABLE OF THE GREAT ICE AGE

Epoch	Years Ago	Interval
	Today	
Recent		Post-glacial (15,000 years)
	15,000	
		Wisconsin glacial (45,000 years)
	60,000	
		Sangamon interglacial (125,000 years)
	185,000	
		Illinoian glacial (100,000 years)
Pleistocene	285,000	
		Yarmouth interglacial (275,000 years)
	560,000	
		Kansan glacial (100,000 years)
	660,000	
		Aftonian interglacial (200,000 years)
	860,000	
		Nebraskan glacial (100,000 years)
	960,000	

The erosion cycle that followed the mid-Pleistocene uplift probably occurred when sea level was lowered during the third, or Illinoian glacial stage. In turn, slight subsidence of the bay depression in late Pleistocene time may have begun as the sea level was rising at the beginning of the subsequent Sangamon interglacial stage. According to Louderback,[24] the bay depression was first inundated by the sea at this time.

The glacial stages which created a new base level for the rivers and streams promoted erosion and stream deposition of gravelly outwash over the lowland area. During the interglacial stages, when the bay depression was partially inundated, extensive blue clay layers were deposited. Extensive gravel and sand layers, such as the Newark, Centerville, and Fremont aquifers, and other water-bearing materials, were probably deposited during the glacial stages of lowered sea level.

Sea level again was lowered, approximately 400 feet, during the Wisconsin glacial stage, which allowed for extensive erosion of the marine and brackish water sediments deposited in the bay depression during the preceding Sangamon interglacial stage. It was during this period of low sea level that the Sacramento River carved the canyon between Carquinez Strait and the Golden Gate to its greatest depth. Today, the bedrock in this canyon lies 381 feet below sea level at the Golden Gate.

Recent History

San Francisco Bay is the result of the most recent inundation of the bay depression which followed the melting of the last ice sheet. Mud has been deposited on the floor of the bay during the last 15,000 to 25,000 years and probably represents the way in which the blue clay aquicludes present at depth were formed.

The rate of deposition of bay mud appears to be fairly rapid, particularly during the years of hydraulic mining in the watershed of the Sacramento River. However, Kvenvolden[22/] has shown by carbon dating that mud only eleven feet beneath the bottom of San Francisco Bay, near Brooks Island, is as much as 6,000 years old.

Evidence exists today that downwarping as well as a rise in sea level is responsible for the latest inundation of the bay. The greatest submergence appears to have been along the west side of the bay, as the Piedmont plain is nearly absent on that side while it is quite wide on the eastern side. Furthermore, the bay mud is considerably thicker along the western side.

Downwarping, or a rise in sea level, may be continuing in parts of the bay region as shown by the inundation of Indian shell mounds located in the marsh along the eastern side of the bay near Emeryville. Carbon dating shows that these mounds are about 3,000 years old; some are now two feet below the high tide line.

While some tectonic subsidence is probably still occurring in Santa Clara Valley, activities of man have produced a much more rapid form of subsidence in the last few years. The continued withdrawal of ground water from the basin has caused a drastic lowering of water levels, resulting in collapse and compaction of fine-grained alluvial sediments with a consequent subsidence of the land surface. Poland and Green[25/] have shown that between 1933 and 1959, a bench mark in San Jose subsided 9.04 feet. The continued lowering of ground water levels between 1959 and 1965 resulted in an additional 3.5 feet of subsidence.

CHAPTER III. PHYSIOGRAPHY

The drainage areas tributary to San Francisco Bay south of the San Mateo Bridge are designated as the South Bay, Livermore, and Sunol Drainage Units on Plate 1. This appendix describes the South Bay Drainage Unit. The Livermore and Sunol Drainage Units are described in Appendix A to Bulletin 118-2, "Evaluation of Ground Water Resources, Livermore Valley".

The South Bay Drainage Unit lies within the Coast Ranges geomorphic province, an area characterized by predominately northwest-trending mountains and valleys covering that portion of the state west of the San Joaquin Valley. The South Bay Drainage Unit is characterized by a broad alluvial valley, sloping northward into San Francisco Bay, and flanked on the east and west by alluvial fans deposited at the foot of the Diablo Range, on the east, and Santa Cruz Mountains on the west.

The physiographic features in the South Bay Drainage Unit are important because they indicate the origin of the sediments comprising the valley alluvium, which in turn, controls the source, occurrence, and movement of ground water within the sediments. The physiographic features are responsible for dividing the valley portion of the South Bay Drainage Unit into the ground water areas and subareas described in Chapter VII.

All of the surface features visible today in the ground water basin are the result of active stream erosion and deposition. For a considerable time, streams have flowed out of the highlands and onto the valley floor at their present locations, depositing great quantities of debris as alluvial fans and outwash plains. The shape of these fans and plains are reflected in the topographic contours shown on Plate 2.

The physiographic divisions shown on Plate 2, have been named after local features such as creeks, towns, and local names. The major physiographic divisions include: the bordering highlands, the bordering foothills, the alluvial aprons and cones, the interior plains, the hills rising above the interior plains, and San Francisco Bay. A description of each of these physiographic divisions is contained in Attachment 2.

Streams draining the Diablo Range and the Santa Cruz Mountains are responsible for deposition in the alluvial areas. The size of the alluvial areas along the eastern and western sides of the bay and the permeability of deposits in these alluvial areas is generally dependent on the size of the watershed area of the tributary stream. The largest streams on the western side of the valley, their watershed areas, and the alluvial areas they influence are listed in Table 2. Similar information for the larger streams draining the eastern side of the valley is listed in Table 3.

TABLE 2
MAJOR WEST SIDE STREAMS

Stream	Watershed Area in square miles	Alluvial Area Influenced
San Francisquito Creek	40	San Francisquito Cone
Matadero Creek	8	West Side Alluvial Apron
Adobe Creek	11	West Side Alluvial Apron
Permanente Creek	8	West Side Alluvial Apron
Stevens Creek	20	West Side Alluvial Apron
Calabazas Creek	4	West Side Alluvial Apron
Saratoga Creek	12	West Side Alluvial Apron
San Tomas Aquinas Creek	5	West Side Alluvial Apron
Los Gatos Creek	44	West Side Alluvial Apron
Guadalupe Creek*	14	West Side Alluvial Apron
Alamitos Creek* and Arroyo Calero*	33	Alamitos Alluvial Area and West Side Alluvial Apron

* These three streams comprise the tributaries of Guadalupe River.

TABLE 3
MAJOR EAST SIDE STREAMS

Stream	Watershed Area in square miles	Alluvial Area Influenced
Alameda Creek	633	Niles Cone
Total of All Stream Watersheds between the Santa Clara County Line and Milpitas	9	Warm Springs and Berryessa Alluvial Aprons
Berryessa Creek	5	Berryessa Cone in the Berryessa Alluvial Apron
Penitencia Creek	23	Penitencia Cone in the Berryessa Alluvial Apron
Total of all Stream Watersheds between Penitencia and Silver Creeks	35	Berryessa and Evergreen Alluvial Aprons
Coyote Creek	193	Santa Teresa Plain

CHAPTER IV. GEOLOGIC FORMATIONS AND THEIR WATER-BEARING CHARACTERISTICS

The geologic formations in the South Bay Drainage Unit have been divided into two groups: nonwater-bearing and water-bearing. This division is based on the ability of the formation to yield water to wells. As used in this report, a water-bearing formation is one that absorbs, transmits, and yields water readily to wells, and conversely, a nonwater-bearing formation is one from which wells produce relatively limited quantities of water. In general, this division can be based also on age, since the water-bearing group includes formations that are geologically young while the nonwater-bearing group includes those formations that are older than Pliocene. The surficial extent of the water-bearing and nonwater-bearing rocks in the South Bay Drainage Unit are presented on Plate 3.

Nonwater-Bearing Rock Units

Rock types within the nonwater-bearing group are exposed in the Santa Cruz and Diablo Highlands and in isolated hills rising above the alluvial plain. These rock types underlie the water-bearing sediments at depths ranging from less than 100 feet to over 1,500 feet and mark the lower limit of ground water production in the South Bay Drainage Unit. The geologic units in this category are the Jurassic to Pliocene marine sediments, serpentine, quartz diorite, and rhyolite.

Nearly all of the rock types comprising the nonwater-bearing formations are consolidated and of low permeability; they do not have primary openings large enough to allow movement of ground water. Ground water contained in these rock types exists largely in secondary openings formed by fractures, joints, shear zones, and faults. The secondary openings provide minimal storage space and avenues for movement of ground water, and explain the ability of these rocks to provide small quantities of water to wells. Because secondary openings are not present uniformly in any given rock type or geographic area, the ability of the rock to yield ground water to wells is quite variable and is dependent largely on local structural conditions. The hydrologic importance of the rocks in the nonwater-bearing group lies primarily in their ability to slowly yield ground water to springs, thus providing perennial flow in many streams draining the highlands that would otherwide be dry in summer.

Domestic water supplies are obtained from nearly all types of rocks in the nonwater-bearing group, springs being the most common source. The springs occur chiefly along faults and fractures and at contacts between different rock types. Shallow wells are found at most of the ranches in the hills where spring water is not available. Wells may yield fair amounts of water in local areas where geologic structures and rock types are favorable. It is likely that the nonwater-bearing rocks transmit small quantities of ground water to adjacent water-bearing sediments in the form of subsurface underflow.

The quality of ground water in the rocks of the nonwater-bearing group is often poor. Most of these rocks are of marine origin and consequently still retain some of the salts of the original connate waters. The salts in most of the coarser-grained facies have been leached out and the rocks now contain small quantities of good quality ground water. Slow migration of the salts from the fine-grained rocks into adjacent ground water is still taking place. Mineralized water in Alum Rock Park, an important tourist attraction since the 1890's, probably originated in this way. Wells present in the Evergreen alluvial apron often contain poor quality water that probably originated in the Cretaceous shales exposed to the east along the flanks of the Diablo Highland.

Deep wells in the San Mateo and Palo Alto areas have been plagued periodically in past years by salt water conditions. According to local opinion, this salt water problem is the result of shallow intrusion from San Francisco Bay. However, some of this salinity may originate in the older nonwater-bearing formations buried beneath the alluvium. Evidence to support this view is shown on the electric log of well 5S/2W-31J80, drilled to 1,040 feet in Palo Alto. The electric log indicated that the sediments contained salt water down to 100 feet, good quality water to 280 feet, then there was a progressive increase in the salt content of the water that reached a calculated concentration of 3,800 parts per million sodium chloride at the bottom of the well. Saline water was encountered at a depth of 460 feet in thin alluvial sand layers less than three feet above the contact with Franciscan chert, in test hole 5S/2W-24B1, drilled near Mowry Slough.

Water-Bearing Units

The sediments comprising the water-bearing units are unconsolidated to semi-consolidated. In contrast to the older nonwater-bearing rocks, the water-bearing units contain ground water in the primary openings between the clastic grains. These grains range in size from clay to silt, sand, and gravel, and reach a maximum of boulder size in certain areas.

The water-bearing materials fall into two groups: the Santa Clara Formation of Plio-Pleistocene age, and Quaternary alluvium of Pleistocene and Recent age.

Santa Clara Formation

The Santa Clara Formation is exposed most prominently in the Mission and Saratoga Uplands. Several other small exposures lie at the base of the Diablo and Santa Cruz Highlands, as shown on Plate 3. The formation underlies the younger Quaternary alluvium and rests unconformably on formations of the nonwater-bearing group. The Santa Clara Formation has been mildly deformed, exhibiting folding on the east side of the basin, and faulting on the west side.

Crittenden 13/ states that exposures of the Santa Clara Formation along the eastern side of the basin, between Warm Springs and Penitencia Creek, show a very consistent character of obscurely bedded, poorly sorted, pebbly sandstone, siltstone, or clay. In addition, exposures show the effects of multiple and continued sliding, such as chaotic bedding and curved slickensided surfaces.

In the Mission Upland, exposures of the Santa Clara Formation in several sand and gravel quarries show that well-sorted gravel lenses with practically no fines occur up to several feet thick and many feet long. These beds appear to be very permeable and if they are common throughout the Mission Upland, they may account for the relatively high production of some wells in that area. Some gravel beds have yielded the bones of large mammals of Pleistocene age, thereby establishing at least a portion of the Santa Clara Formation as being no older than lower Pleistocene.

Stream cross-bedding, scour and fill, lenticular shapes of beds, and the extreme range in sorting seen in the Mission Upland, all point to stream deposition. The presence of abundant vertebrate remains and the lack of marine fossils also suggests a continental environment. Branner and others 4/ reported several fresh water mollusks from the Santa Clara Formation which also supports a continental depositional environment.

On the west side of the basin, Bailey and Everhart 2/ described the Santa Clara Formation in the Los Gatos area as a poorly sorted, irregularly bedded alluvial material ranging from coarse silt to boulders over two feet in diameter. Although few exposures were observed by these authors, the steepest dip was recorded as 20 degrees to the east.

Tolman 33/ described the Santa Clara Formation, as exposed on Stevens Creek, as silt-cemented sands and conglomerates of low permeability. He pointed out that the silt in this portion of the formation is of primary origin and is not a product of recent weathering as had been previously assumed.

The above observations suggest that the Santa Clara Formation dips consistently toward the east at from 10 to 30 degrees; hence the older portion of the formation should be exposed along its western contact with the nonwater-bearing rocks. The fact that the Santa Clara Formation is fine-grained along this western contact, and that lower Pleistocene portions in the Mission Upland are quite permeable suggests that this formation became coarser-grained and more permeable with time. Well data indicate that the permeability tends to increase from west to east across the Saratoga Upland, and the highest production of wells in the Santa Clara Formation is reported to be in the Mission Upland on the eastern side of the basin. Beneath the valley proper, well logs show that the sediments tend to decrease in grain size and permeability with depth. This tendency is illustrated by the log of the deepest well in Santa Clara Valley, owned by the San Jose Water Works and located at 17th and Santa Clara Streets in the City of San Jose. This well, which reached a depth of 1,535 feet, showed about 25 percent gravel between 0 and 250 feet, numerous intervals of cemented gravel between 250 and 1,000 feet, and a series of yellow and blue clay intervals with virtually no gravel below 1,000 feet. This log shows that, at least in this area, production is limited to the upper 1,000 feet of material, and suggests that the sediments below 1,535 feet may be unproductive. This information suggests that the fine-grained sediments exposed in the Santa Clara Formation along its extreme western contact may be the same fine-grained section described in logs of deep wells in the City of San Jose.

The Santa Clara Formation is undoubtedly present beneath the Quaternary alluvium in most of the South Bay Drainage Unit. However, the lithologic similarity between these two units largely precludes any clear separation between them on the basis of the well log information available during this investigation. Only occasionally along the margin of the basin, is a separation between these two units possible, as it is here that a rather sharp contrast exists between the grain sizes of these two formations.

The Santa Clara Formation is relatively fine-grained along the western side of the valley where it disappears beneath the alluvium. In contrast, the alluvium in this area is quite permeable as it is very near the point at which vigorous streams emerge from the mountains.

<u>Quaternary Alluvium</u>

Quaternary alluvium is the most important water-bearing formation in the South Bay Drainage Unit. Permeability is generally high; consequently all the large production water wells draw their supply from the alluvium.

The alluvium is composed of gravel, sand, silt, and clay, and various mixtures of these grain sizes, all of which are generally unconsolidated. The sand and gravel deposits have the highest permeability and are thus the major aquifers; conversely, silt and clay layers have low permeability and therefore, form aquicludes.

Alluvium around the margin of the basin was deposited as a series of alluvial fans by streams draining out of the highlands and onto the valley floor. Probably only the most recent alluvial fans are expressed physiographically today.

The more gently sloping central portion of the basin, the San Jose Plain, is underlain by a permeable alluvium laid down by the many streams that merge in the central portion and flow north out of the basin. Coyote Creek has probably contributed most of the permeable alluvium known to underlie the San Jose Plain, which probably accounts for the high ground water production there as compared to that in the bordering alluvial fans.

The San Jose Plain becomes progressively finer-grained toward the north and contains a series of blue clay layers that become increasingly thicker toward San Francisco Bay. These clay layers begin near San Jose and continue northward beneath the bay where they constitute nearly the entire thickness of alluvium. The clay layers are separated by relatively thin fine-grained sand and gravel layers that are distal portions of the bordering alluvial fans. The southern end of San Francisco Bay is underlain by alluvium composed of a mixture of continental sediments deposited by streams from the south and of alluvium deposited in a marine to brackish water environment in pre-existing bays located where San Francisco Bay now lies. The extensive marine clay layers can be traced south in the alluvium to the vicinity of San Jose and contribute to the confinement of ground water beneath the San Jose Alluvial Plain.

The extensive blue clay layers were deposited during inter-glacial periods in a manner similar to the present deposition of bay mud beneath San Francisco Bay. Only in areas where alluvial fan deposition was occurring near the bay, were streams able to carry coarse-grained sediments out into the marine environment. Consequently, it is in areas where no active alluvial fans exist today, that the percentage of clay reaches a maximum in the alluvium. This area of highest clay content is largely marked by the southern margin of the Bay Plain.

Beneath San Francisco Bay, the buried clay layers appear to be separated by relatively thin, but very widespread, flat layers of sand and gravel. These layers were probably deposited during the past glacial periods when the lowering of sea level allowed streams draining the highlands to deposit sand and gravel layers progressively farther toward the center of the basin, on top of the previously deposited thick clay layers.

The extent and thickness of the various layers of clay, gravel, and sand are shown in perspective on Plate 4. The panel diagram shown on this plate is a composite of several geologic cross-sections.

The great thickness of fine-grained marine and brackish water deposits that exist in the alluvium beneath the southern end of San Francisco Bay results in an areal division of the ground water basin into three permeable areas, between which, little if any, exchange of ground water occurs. The three areas are shown generally by the three groups of specific capacity contours on Plate 5. A division between these three areas also can be traced on Plate 2 by following the outer limits of the Niles Cone, the San Francisquito Cone, and the West Side Alluvial area.

The depth to the base of Quaternary alluvium cannot be readily determined, as the similarity in lithology between it and the underlying Santa Clara Formation precludes distinguishing these two units on the basis of the data available. However, well log descriptions make it possible to distinguish in a general way between the water-bearing group and nonwater-bearing rocks at depth. A determination of thickness of water-bearing materials has been attempted and the results are presented on Plate 10. This plate shows well log information in both a positive and negative way. That is, the depth to nonwater-bearing rocks, as reported on well logs, together with the depth of the deepest well in each section that does not report nonwater-bearing rock.

CHAPTER V. GEOLOGIC STRUCTURE

Regional Features

Horizontal compression of the crust of the earth in the Coast Ranges physiographic province has created the major structures now characterized by northwest-trending faults, mountain ranges, and valley depressions. The South Bay Ground Water Basin occupies the southern portion of a major structural depression between the Diablo Range, on the east, and Santa Cruz Mountains on the west. The three largest faults in the region lie on either side of the basin, the great San Andreas fault zone near the western side and the Hayward and Calaveras faults along the eastern side. A combination of movement along these faults and tectonic downwarping of the intervening area is responsible for the formation of the bay depression.

Superimposed on the major structural trough are many minor parallel northwest-trending features important to the occurrence and movement of ground water in the South Bay Ground Water Basin. Faulting has caused the bedrock beneath the basin to be broken into a series of parallel blocks, some of which have subsided and others which have risen. Downwarping of the bedrock surface to considerable depths, primarily in the San Jose area, has allowed the gradual accumulation of a thick section of overlying water-bearing sediments. Consequently, the depth to bedrock, primarily a structural feature, is important to this study since it points out areas where ground water may or may not occur.

Faults

Faults have been important in shaping the Santa Clara Valley. Besides the great San Andreas fault zone and the Hayward and Calaveras fault systems, other faults have been mapped in both the Diablo and Santa Cruz Highlands. Many of the faults in the nonwater-bearing rocks of the highlands are very old. For instance, the Ben Trovato and Coyote Peak shear zones are reported by Bailey and Everhart [2/] to be older than middle Miocene, and apparently are no longer active. Not all of the faults shown on Plate 3 are active structural features at this time.

There are three main fault systems in the area of investigation: Shannon, Silver Creek, and Hayward. There are also other lesser fault systems buried beneath the valley alluvium.

Shannon Fault

The Shannon fault is a recent feature trending along the southwestern edge of the basin between the Ben Trovato and Coyote Peak fault zones. Five parallel branches of this fault, at its northward extension, cut the Santa Clara Formation at the south end of the Saratoga Upland. These branches all offset the Santa Clara Formation with small displacement and appear to be normal faults.

The northernmost branch dips to the northeast, according to Bailey and Everhart,[2/] who report that the Shannon fault is the most important post-Cretaceous fault in the southwestern portion of the area. It may continue farther north than shown on Plate 3. Taylor [30/] shows one branch of the Shannon fault extending northwesterly through the Saratoga Upland one and one-half miles east of and parallel to the contact between the Franciscan and the Santa Clara Formations. Taylor's geologic map shows the extension of this fault joining a system of thrust faults mapped by Dibblee [16] along the contact between Tertiary and Franciscan rocks in the hills west of Los Altos.

Additional branches of the Shannon fault may exist beneath the alluvium northeast of the Saratoga Upland and thus may account for a buried hillfront that probably exists in this area.

Silver Creek Fault

The Silver Creek fault, located in the southeastern portion of the basin, like the Shannon fault displaces the Santa Clara Formation. Where exposed, this fault marks the contact between Santa Clara sediments and rocks of the Franciscan Group. Its trace is marked by both physiographic and stratigraphic features southwesterly of the basin to a point west of Morgan Hill where it joins the Calaveras fault.

Crittenden [13] presents evidence that one small branch of the fault thrusts Franciscan rocks eastward over the Packwood Gravels. In this same area, the main trace dips steeply east and is apparently reversed. Crittenden also suggests that the Silver Creek fault continued northward along its strike beneath the alluvium and cites as evidence two earthquake epicenters along this alignment. On the basis of gravity work, Taylor postulated two parallel branches of the Silver Creek fault passing northward on the east side of Coyote Hills. However, the results of the gravity survey conducted during this investigation show that the Silver Creek fault extends north as a single trace beneath the alluvium, passing about one and one-half miles east of the Coyote Hills.

The buried extension of the Silver Creek fault is not known to have any effect on ground water, but it undoubtedly offsets the Plio-Pleistocene sediments beneath the valley, just as it does in exposures to the south.

Hayward Fault

The Hayward fault runs along the base of the Diablo Highland and crosses the upper portion of the Niles Cone, where it forms an effective barrier to the lateral movement of ground water. Radbruch 26/ described movement along the Hayward fault, which caused the great earthquakes of 1836 and 1868. Slow creep movement has been described by Radbruch and others 27/ along the trace of the Hayward fault showing that this fault is still active today.

The Hayward fault extends from Berkeley south to the Alameda-Santa Clara County line. Prominent topographic features trace its presence along the foot of the Berkeley Hills south to Hayward where it leaves the mountain front and passes beneath the alluvium of the Niles Cone. The fault trace continues south of Irvington, where it is marked by a well-formed, west-facing scarp up to 200 feet in height and consisting of unconsolidated sediments of the Santa Clara Formation. Topographic evidence of the fault continues to just south of Warm Springs, where it appears to die out beneath the alluvium.

Where the fault crosses the Niles Cone, prominent surface features include elongated depressions flanked on the southwestern side by elongated hills from five to twenty feet in height. The most recent fault movement in the Niles area has caused the land on the northeastern side to be depressed 20 to 25 feet relative to the opposite side. Historically however, the direction of vertical movement along this fault has been in just the opposite direction.

While the fault zone is normally not exposed, several individuals have described its appearance in excavations. In 1951, an exposure one half mile southwest of Niles was examined by Thomas.[31/] Here the fault appeared as a vertical clayey-sand dike about one foot wide, containing scattered pebbles and cobbles. The dike looked like material which might have been forced up from below while in a saturated state. While this exposure appeared to be only a moderately effective deterrent to the flow of ground water, it is likely that similar material may be transformed at depth into relatively impermeable gouge by movement along the fault. The fault was exposed about one mile northeast of Warm Springs for a short period during construction of a new pipeline for the San Francisco Water Department. This exposure, also described by Thomas,[31/] was located about 50 feet south of the pipeline crossing with the Mission Boulevard. The fault zone appeared as a vertical clay dike composed of highly sheared and contorted clay derived from the Santa Clara Formation and about three feet wide. Adjacent beds of clay and sand in the Santa Clara Formation were highly fractured and contorted, but these effects gradually diminished and were no longer evident 20 feet away from the fault zone.

The gradual creep that has been observed recently along the Hayward fault is probably not a new phenomenon. Slow movement, as well as rapid earthquake-producing movement, could shear the alluvial material through which the fault passes. The offsetting of gravel aquifers and the development of a clay gouge could easily occur along such an actively moving fault.

Faults Hidden Beneath the Alluvium

In addition to the three main fault systems, the gravity survey conducted during this investigation revealed the presence of three other faults buried beneath the alluvium. All are shown on Plate 3. All of these faults offset buried Franciscan bedrock so that the depth to bedrock between them is quite variable. These faults are not known to have any direct effect on the lateral movement of ground water. However, they are responsible for shallow depths of alluvium, where the bedrock blocks have been brought relatively near the ground surface.

Bedrock Surface Beneath the Basin

The depth to bedrock in the northern portion of the ground water basin is illustrated by the contours shown on Plate 3. These contours show that the buried bedrock surface generally has the configuration of a series of five parallel blocks. As a result of differential movement, each block lies at a different depth.

The block having the highest bedrock elevation outcrops at Coyote Hills and at Oak Hill. Another block of relatively high bedrock extends from San Mateo County southward, passing beneath Palo Alto. The three other blocks are buried beneath a relatively thick cover of alluvium.

The most significant feature of the contours shown on Plate 2 is the bedrock high crossing the bay depression in the vicinity of Coyote Hills. Along this high, Franciscan bedrock is never more than about 800 feet beneath the land surface. In contrast, to the south the contours increase in depth rapidly, suggesting that bedrock is buried very deeply in the San Jose area.

Water wells which encountered hard rock in the vicinity of the bedrock high are shown on Plate 3. This hard rock is probably Franciscan sandstone, shale, or serpentine. It was reported to be at about the same depths as represented by the bedrock contours. The logs of most of the wells show that nearly the entire thickness of sediments penetrated are water-bearing. Thus, across this high, there exists only a minor thickness of nonwater-bearing pre-Pliocene rocks overlying the Franciscan bedrock. During deposition of the water-bearing sediments, streams must have drained to the north across this bedrock high; consequently, barring a great deal of tectonic subsidence, the water-bearing sediments in the southern portion of the basin may not be much thicker than the maximum depth to bedrock across the buried bedrock high.

During deposition of the water-bearing sequence, the land surface in the San Jose area must have been higher in elevation than the bedrock high, in order for drainage to the north to have occurred. Therefore, unless a great deal of subsidence has occurred since most of the water-bearing sediments were deposited, a considerable thickness of Cretaceous to Pliocene rocks probably exists as a wedge between the Franciscan bedrock and the overlying water-bearing sediments in that portion of the basin south of San Francisco Bay.

An exception to this may be the partially buried fault block of which Coyote Hills is a part. This block may not have a wedge of Cretaceous to Pliocene rocks overlying the Franciscan bedrock, since nowhere in the exposed portions are there outcrops of rocks in this age group. In contrast, the adjacent fault blocks show greater depths to Franciscan rocks as well as numerous outcrops in the younger age group.

On Plate 3 the contours show only the broad general features of the buried bedrock surface. Evidence suggests that this surface is much more irregular, and if not mountainous, certainly very hilly. Evidence includes these observations: (1) Coyote Hills and several other outcrops of Franciscan bedrock rising above the alluvium, are quite rugged in nature; (2) results of the Sparker Survey in San Francisco Bay reveal that areas along Redwood Creek, Coyote Creek, and Alviso Slough are underlain by an irregular, bumpy reflective horizon believed to be Franciscan bedrock; and (3) bedrock exposed in the Diablo and Santa Cruz Highlands is quite irregular and mountainous. It follows that the buried bedrock surface would appear quite rugged if all the alluvial material were stripped away.

CHAPTER VI. THE GEOLOGIC INVESTIGATION

To determine the geologic conditions affecting ground water in the study area, five phases of study were undertaken and completed: (1) collection and analysis of available data, (2) geophysical surveys, (3) test hole drilling and installation of test wells, (4) water level measurements, and (5) aquifer tests for permeability determination.

The initial phase of the collection and analysis of data, showed that there was a paucity of geologic and hydrologic information about the area beneath the Bay Plain and south San Francisco Bay. This area was believed to be the connecting link between ground water producing areas in Alameda, San Mateo and Santa Clara counties. To study the entire region, more information was needed in this critical area. Therefore, geophysical surveys, test hole drilling and installation of test wells, water level measurements and aquifer pump tests were performed to obtain this information.

Each of the five phases of study was actually a small investigation in itself. They are described in considerable detail because they represent original contributions to the state of knowledge about the basin, and as such are valuable beyond the immediate scope of this investigation.

Collection and Analysis of Available Data

During the first phase of study, all available data pertaining to the geology and ground water hydrology of the study area was collected, including geologic maps and reports, well logs, water well characteristics, water levels, and water quality records.

The data were obtained principally from records of water agencies in and near the area, the U.S. Public Health Service, University Ph.D. and Masters theses, and the well logs of 15 water well drilling contractors. This information was integrated with that already in the Department's basic data file and became the basis for subsequent phases of the investigation. Basic data collected during this investigation is now on file in the San Francisco Bay District office in Vallejo.

Geologic Data

Approximately 5,000 well logs from all water well drilling contractors known to have been active in the basin were obtained for wells located throughout the Bay area, from Sonoma County on the north, to Monterey County on the south. Of this total, approximately 2,500 well logs in the study area were located accurately by field checking in many instances, and plotted on $7\frac{1}{2}$-minute quadrangles. Most of the well logs in Alameda County were obtained from the basic data files for Bulletin No. 81.7/ Logs in Santa Clara County were supplemented by the basic data obtained for Bulletin No. 7, 9/ and the well records of the Santa Clara Valley Water Conservation District. In all cases, newly acquired well data were correlated with the Department's water well log files. Water well logs were the key source of available subsurface information used in the geologic investigation.

To analyze the well log data, a means of presenting this data in concise form was required. A geologic peg model was considered to be the most practical means of presenting the complete subsurface picture of the basin.

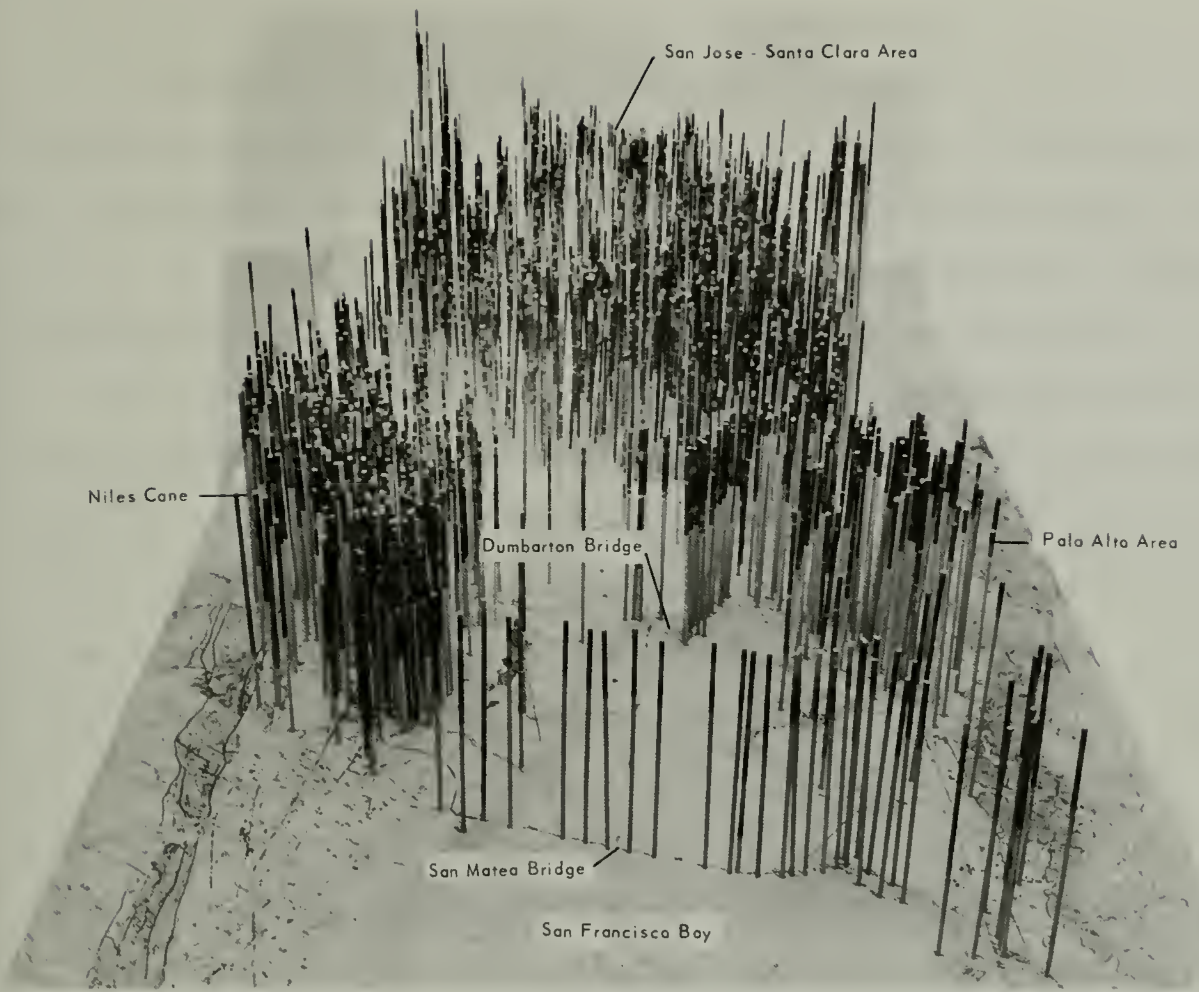


Figure 1. Geologic peg model of South Bay Ground Water Basin. Looking South.

The peg model, shown in Figure 1, has approximately 1,200 wooden dowels, each representing a water well, mounted vertically in holes drilled into a five by nine foot board showing a geologic map of the area. The horizontal map scale is 1 inch to 2,000 feet, and the vertical peg scale is 1 inch to 50 feet, giving the model a vertical exaggeration of 40:1. Each peg was painted with bands of color corresponding to the type of sediments commonly reported on well driller's logs. The colors and the sediments they represent include red for gravel, yellow for sand, green for sandy clay and clayey sand, blue for silt or clay, and alternating vertical stripes for combinations of sediments.

The surface of the peg board represented a datum plane of 600 feet below sea level. Because the majority of the water wells do not reach this depth, the selection of this datum plane enabled all but the very deepest wells to be shown on the peg model. However, because of space limitations, only the deeper wells were shown, and they were selected because they were spaced at intervals convenient for study. In areas where coverage was scarce all well logs were used.

Presenting the well log data in this three dimensional manner, showed that many apparent discrepancies in driller's descriptions of sediments were merely differences in descriptive terminology. When all the wells were positioned in proper relation to each other, these discrepancies were largely reconciled and a clear picture of the true nature of the deposits emerged.

The peg model has been of greatest benefit in the northern portion of the basin where it shows the lateral extent of individual aquifers and aquicludes. Areas of similar lithology are immediately apparent on the peg model; for instance, in the Alviso area, the high clay content is shown by the dominance of blue. In contrast, in the West Side Area, the lack of continuous layers is apparent by the lack of any predominant color. The areal extent of aquifers and the lithologic similarities would have been very difficult to visualize on geologic sections alone.

The peg model aided in the correlation of individual aquifers and aquicludes within the alluvial deposits of the Niles Cone, south San Francisco Bay, Bay Plain, and the central part of the San Jose Plain as far south as San Jose. This area of correlation roughly coincides with, but is somewhat smaller than the original area of flowing wells outlined by Clark.[12/] Correlation generally was not possible on the remainder of the ground water basin because of the limited extent of the aquifers.

The 40:1 vertical exaggeration of the peg model made it difficult to correlate beds that dipped more than about 1°, as at this exaggeration such a dip would plunge about 30°. In spite of this limitation, it was possible to correlate on the peg model many of the aquifers beneath a large portion of the area.

In addition to the peg model, a map was prepared which indicates the approximate depth to the base of the water-bearing sediments. This map is presented as Plate 4. From this map, the depth to nonwater-bearing rock can be determined in areas where wells are known to bottom in these materials. In the central portion of the basin, where wells do not encounter nonwater-bearing rock, the map indicates the greatest well depth per section for which well log data are available.

Forty-three geologic cross-sections were developed for use during this investigation. In addition, 14 geologic cross-sections developed for Bulletin No. 81, and one geologic cross-section along the alignment of the San Mateo Bridge were used. The cross-sections were developed largely from water well logs.

The geologic panel diagram shown on Plate 5, is based on 15 of the more significant geologic cross-sections. The panel diagram enables the viewer to see the entire basin at one time and to determine the relationship between the different panels. The top of each panel represents ground surface; the base represents an elevation of 600 feet below sea level.

Ground Water Data

Most of the ground water level records used in this investigation were obtained from previous investigations, from water districts, from other agencies, and from a continuing cooperative well measuring program. The measuring program is comprised of a net of specific wells covering the entire basin. The wells are measured semi-annually, in Spring and Fall, by the Department or one of the several cooperating local agencies. Continuous water level records also were obtained for specific areas adjacent to the South Bay, where such data are scarce, by placing Stevens Type F water stage recorders on test wells drilled by the Department.

The water quality data obtained from previous reports, well drilling contractors, corporations, cities, and water districts were studied and used as the basis for a detailed water quality survey of the area around the South Bay. During Spring 1963 and Spring 1964 analyses for chloride ion concentration, conductivity, and total hardness were made of well water in this area to detect any southward migration of poor quality ground water immediately south of the bay into Santa Clara County. No such migration was observed during the one-year period.

Pump efficiency test data were obtained principally from the records of the Pacific Gas and Electric Company and several well drilling contractors. These data show the rate of pumping and the corresponding drawdown in wells; values which are needed to determine specific capacity. Specific capacity values obtained throughout the ground water basin are contoured on Plate 6.

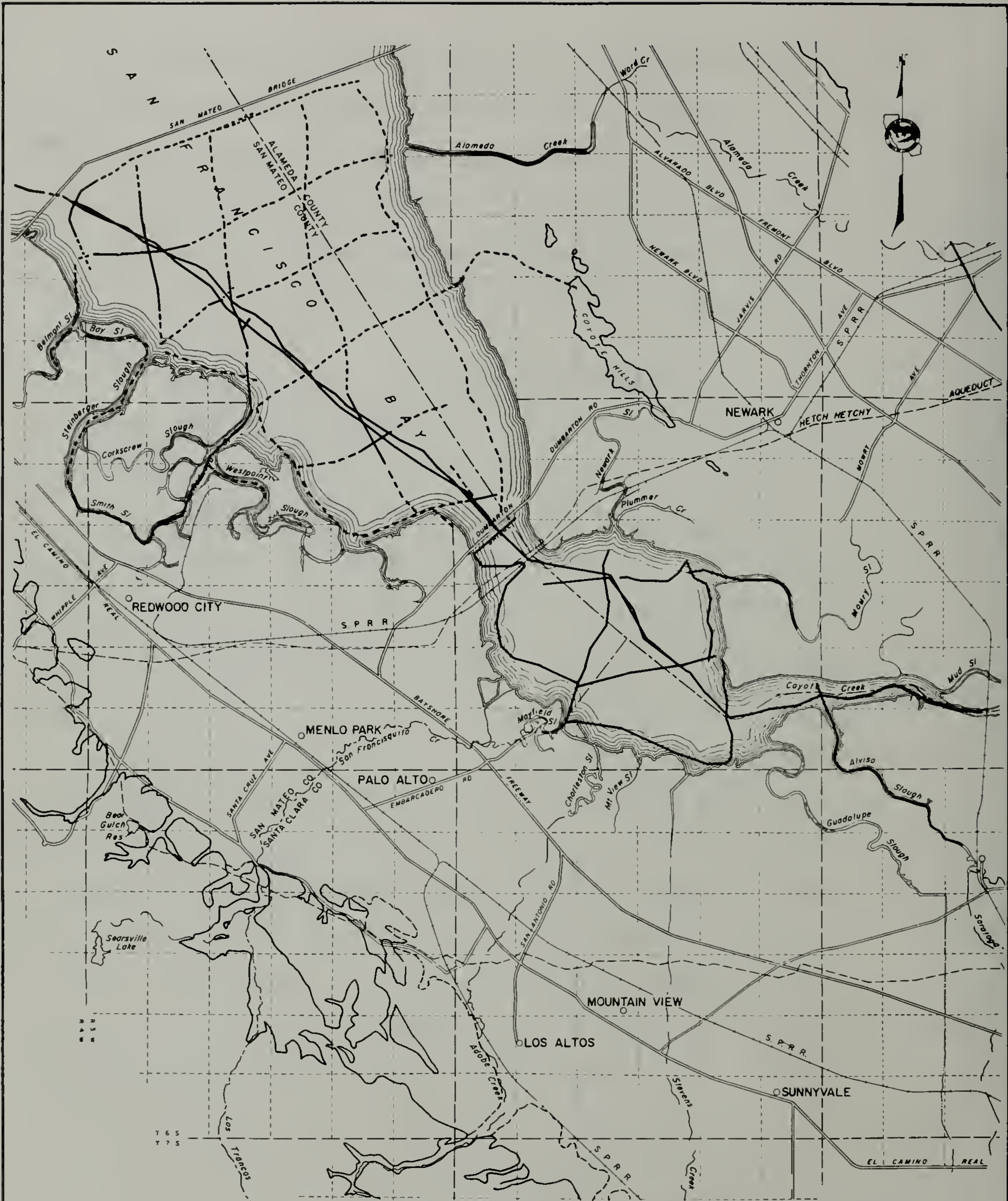
Geophysical Surveys

Three types of geophysical surveys were performed during this investigation. The surveys were used to assist in determining the nature and total depth of the water-bearing formations. The surveys included seismic, gravity, and magnetometer, each of which is briefly discussed below. A detailed discussion of the theory, equipment, field procedures, and results of the surveys is presented in Attachment 3 to this appendix.

Seismic Surveys

Two seismic survey methods were used during this investigation. The Sparker method was used to determine subsurface conditions in areas beneath the surface of the bay. The refraction method was used to determine conditions near Coyote Hills and Mowry Slough.

Sparker Survey. A Sparker survey is a continuous marine seismic reflection technique that is similar in principle to an echo sounder but uses a high voltage electrical spark as an energy source. A series of traverses were run in the form of a grid across San Francisco Bay south of the San Mateo Bridge and also along the deeper sloughs meandering through the Bay Plain. The traverse lines are shown on Figure 2.



LEGEND

—— SPARKER SURVEY TRAVERSE LINE GOOD RESPONSE

----- SPARKER SURVEY TRAVERSE LINE POOR RESPONSE

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES – SOUTH BAY

SPARKER SURVEY TRAVERSE
1964

SCALE OF MILES
1 0 1 2 3

The data developed during the Sparker survey was somewhat inconclusive. Reflected energy was received only in locations where the bay mud was thin or had been removed by dredging. Bay mud, which occurs as a thick blanket beneath nearly all of San Francisco Bay, acts as an acoustical sponge which absorbs rather than reflects the seismic waves generated by the sparker. Bacause of this, reliable records could be obtained only along the main ship channel, Redwood Creek, Coyote Creek, and certain portions of the bay south of Dumbarton Bridge. A depth to the Franciscan Formation bedrock was indicated in most of these areas.

The Sparker profiles showed that the bay bottom is underlain by a series of approximately horizontal beds. The base of the bay mud appeared to be the most continuous horizon. Some of the profiles showed small microstructures truncated by the base of the bay mud.

Along both the Redwood Creek and Coyote Creek areas, strong reflections were recorded which appeared different from those in most of the other areas. These reflections showed the high relief characteristic of a rugged erosional surface. The strong reflections at Redwood Creek represent Franciscan bedrock, as confirmed by logs of nearby wells. The cause of equally strong reflections along Coyote Creek could not be determined. A buried southward extension of the Coyote Hills is a reasonable explanation.

Refraction Survey. A refraction survey was conducted in the area near Coyote Hills to determine the extent of the buried extension of these hills. A second refraction survey was made in the test hole drilled at Mowry Slough to determine the velocities of seismic waves in sediments beneath the bay. These velocities were used in interpreting the results of the Sparker survey.

Nine seismic traverses were made, as shown on Plate 9. Seismic velocities of bedrock were established at line A, which was run on serpentine, and at line B, which was run on broken Franciscan chert. Lines F, G, and the two downhole lines at the Mowry Slough test hole determined the velocities of the sediments beneath the bay and adjacent marshland. Velocities were determined for all of these materials:

Material	Velocity
Serpentine	8,500 feet per second
Franciscan chert	4,500 feet per second
Bay mud	1,800 feet per second
Saturated sediments beneath the mud	4,400-6,000 feet per second

Five seismic lines: C, D, E, H, and I, were run to determine the depth to bedrock. These were run across the magnetic highs inferred from the magnetometer traverses.

To determine the seismic velocity of materials beneath the bay, geophones were installed in the Mowry Slough test hole. This seismic test indicated that these sediments have a velocity of about 6,000 feet per second at a depth of 170 feet.

Gravity Survey

A gravity survey was made along the eastern and southern shores of San Francisco Bay. Changes in the force of gravity caused by changes in rock densities were used to determine total depth to the Franciscan Formation, which comprises bedrock in the basin.

The data developed was used to prepare a Bouguer gravity anomaly contour map and a residual gravity map. Following is a brief description of each of these maps. They are described in some detail in Attachment 3 of this appendix.

Bouguer Gravity Map. The Bouguer gravity anomaly values were combined with those previously obtained by Taylor,[30] Greve,[19] and Chapman,[10] to prepare a gravity map of the south bay area having a two milligal contour interval. This map, Plate 6, is characterized by a series of northwest-trending anomalies and a regional decrease in gravity toward the northeast.

Greve estimated that the regional gradient in the San Francisco Bay area decreases at about 1.5 milligals per mile toward the northeast. This change in gravity may be caused either by the transition from an oceanic to a continental crust, or by an offset in the crustal layer at a depth of about 13 kilometers. Although the present study was concerned only with local anomalies, it was necessary to remove this regional gradient from the calculations in order to isolate these anomalies for interpretation.

Prominent local features of the gravity map, shown on Plate 8, include the following:

1. The Coyote Hills high trends southeastward from Coyote Hills to the vicinity of Alviso, where a thickness of 1,000 feet of younger materials overlie Franciscan bedrock. This feature gradually diminishes southeast of Alviso, in the direction of the Niles-Evergreen gravity low. Northwest of the Coyote Hills, the anomaly turns abruptly to the northeast and diminishes in magnitude. This anomaly is evidently an expression of the buried northern extension of Franciscan rocks exposed in the Coyote Hills.

2. The Oak Hill-Moffett Field high was first suggested by Taylor who discovered a gravity anomaly in the vicinity of Oak Hill, southeast of San Jose. The present survey indicates that the anomaly continues northwestward to Moffett Field, where the depth to Franciscan bedrock is about 1,200 feet. The gravity high near Dumbarton Point, still farther toward the northwest could be a northwesterly continuation of this anomaly. This anomaly is apparently a buried northward extension of the Franciscan rocks exposed at Oak Hill.

3. The Redwood City-Palo Alto high trends southeastward from Redwood City to Mountain View. Here the anomaly appears to die out in the direction of the Cupertino low, located to the southeast. Franciscan rocks are exposed along this anomaly in Redwood City.

4. The Niles-Evergreen low is a very pronounced northwest-trending negative anomaly which was first outlined by Taylor and subsequently described by Chapman. It trends from near Niles, where there are about 5,000 feet of younger rocks to the vicinity of Evergreen, where the thickness of sediments overlying bedrock is at least 7,000 feet.

5. The Cupertino low described by Taylor and Chapman is a nearly circular anomaly centered just southeast of Cupertino. A narrow, northwest-trending extension of this anomaly passes in the vicinity of Stanford University to a point southeast of Redwood City. This Cupertino low is believed to represent a section of post-Franciscan sedimentary rocks having a total thickness of at least 5,000 feet.

The Bouguer gravity data developed for Plate 8 were used in preparing the four gravity profiles shown on Plate 9.

Residual Gravity Map. Plate 10 is a residual gravity map of the area surveyed. Such a map, although qualitative, is useful because it tends to emphasize local anomalies and minimize the regional features.

The most important features shown on this map are:

1. A nearly linear northwest-trending positive anomaly that extends from Coyote Hills to the edge of the map area southeast of Alviso. This anomaly probably represents the subsurface continuation of the Coyote Hills basement high. A northwestward extension of the anomaly in the vicinity of Alvarado is also shown.

2. Positive anomalies in the Dumbarton Point and Moffett Field areas correspond with anomalies shown in the same areas on the Bouguer gravity map. These anomalies are believed to represent basement highs.

3. A positive anomaly is located in the area just east of Drawbridge, on Mud Slough. This anomaly trends just west of north and corresponds in position to the edge of the west, upthrown, block of a fault shown on Plate 3.

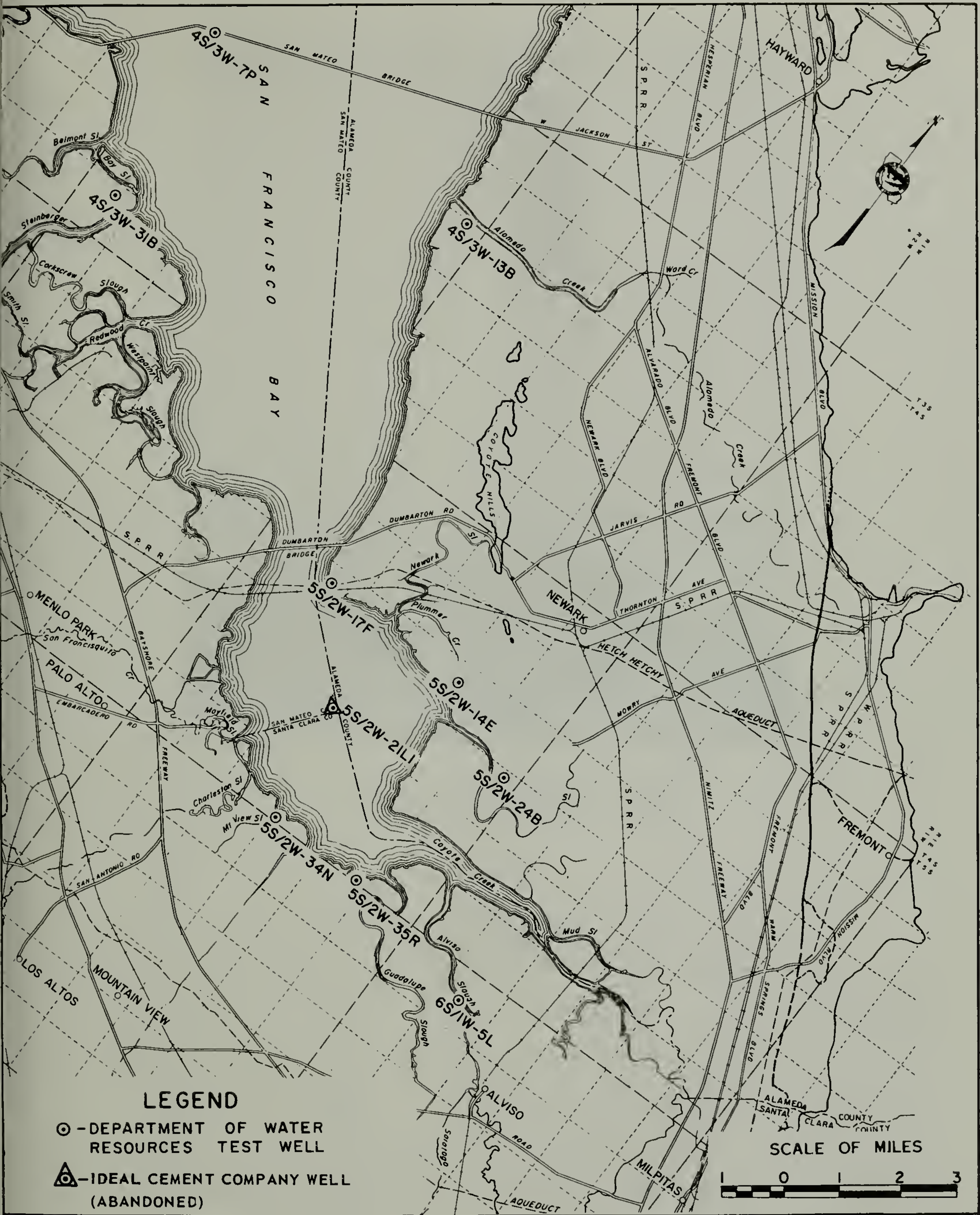
Magnetometer Survey

A Magnetometer Survey was made to measure the total intensity of the earth's magnetic field in the area north and south of Coyote Hills. The association of serpentine with sediments of the Franciscan Formation in the Coyote Hills area made this survey a logical means of tracing the buried extension of the Coyote Hills both north and south of their present outcrop area.

The survey was conducted with a portable Varian M-49 proton precession magnetometer. Readings were recorded every 0.01 mile and ranged between 51,020 and 51,886 gammas. Initially, seven traverses covering a total of four miles were made to determine the position of bedrock highs. These traverses were used to establish the locations of the seismic survey. Later, the traverses were extended and new ones were established until a total of 21 traverses had been made. Plate 7 shows the lines of the survey and presents the results in the form of lines of equal intensity of the earth's total magnetic field. The area covered by the survey extends from the San Mateo Bridge, on the north, to Alviso, on the south, and from the edge of the bay, on the west, to Nimitz Freeway, on the east. Most of the traverses were run in an east-west direction normal to the trend of Coyote Hills.

Test Hole Drilling

During the summers of 1963 and 1964, a series of 10 deep test holes were drilled in the marshland surrounding south San Francisco Bay. These holes provided clues to the subsurface geology in an area almost totally lacking in such data. Each hole was eight inches in diameter and was drilled with a Failing 1500 rotary drill rig. The purpose of drilling these test holes was threefold: to explore the subsurface geology; to provide control for the Sparker survey; and to provide a location in which to install a series of piezometers which could be used to monitor water quality and water level fluctuations in individual aquifers. The locations of the of the test holes are shown on Figure 3 and their number, designation, and depth are shown on Table 4. Figure 4 depicts the drill setup of test hole 5S/2W-34N.



LOCATION OF TEST HOLES

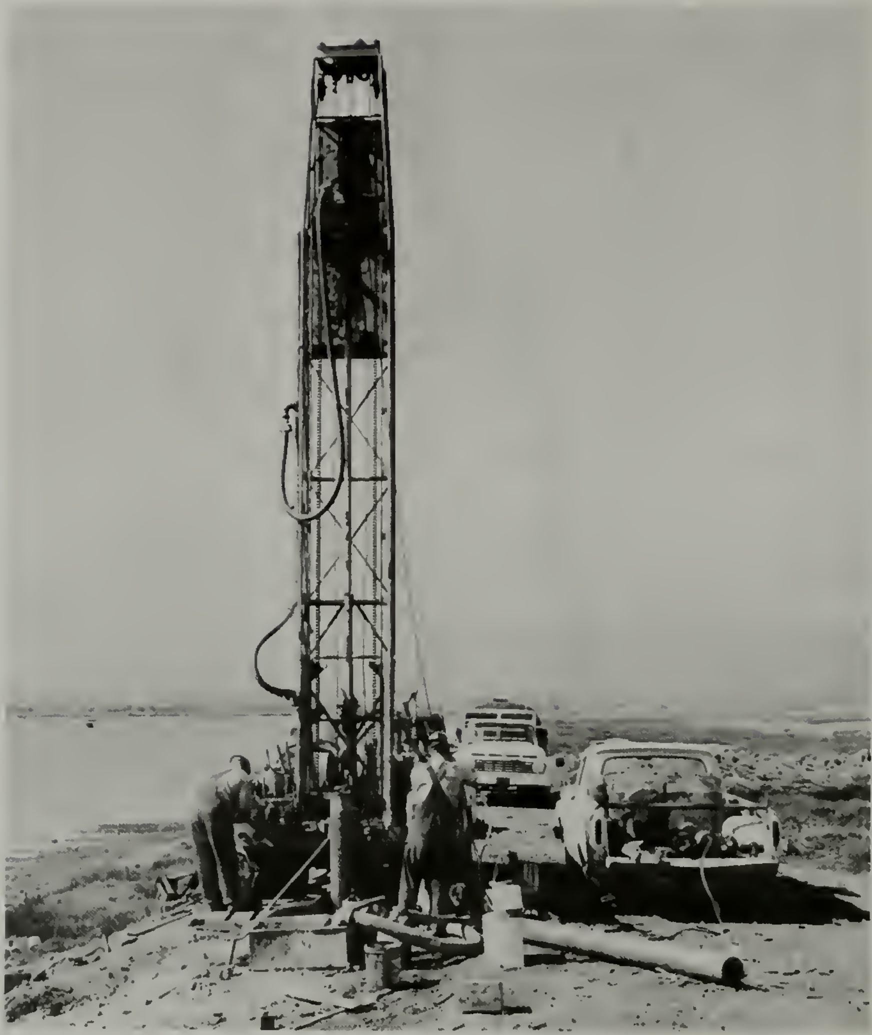


Figure 4. Drilling test hole 5S/2W-34N, at Mountain View Slough.

TABLE 4
TEST HOLES DRILLED IN THE SOUTH BAY AREA

Test Hole Location Number	Nearest Geographic Feature	Total Depth in Feet	Electric Log Run
4S/3W-7Q	San Mateo Bridge	525	Yes
4S/3W-13B	Alameda Creek	441	Yes
4S/3W-31B	Radio Station KNBR	507	Yes
5S/2W-14E	Plummer Creek	232	No
5S/2W-14E	Plummer Creek	418	Yes
5S/2W-17F	Dumbarton Point	433	Yes
5S/2W-24B	Mowry Slough	497	Yes
5S/2W-34N	Mt. View Slough	262	Yes
5S/2W-35R	Moffett Field	502	Yes
6S/1W-5L	Alviso Slough	416	Yes

Each test hole was originally planned for a depth of 500 feet. This depth would be sufficient to penetrate the most important aquifers in the ground water basin. However, six of the test holes were terminated short of this depth because of very slow drilling in the tough, clay-rich sediments.

Bedrock was encountered only in the Mowry Slough test hole, but a number of very tough drilling zones were penetrated in other holes that suggested the presence of several erosion surfaces within the alluvial sediments.

The dashed contours on Plate 3, which represent depth to Franciscan bedrock based on the gravity survey, suggest that the area near Dumbarton Point is underlain by these rocks at a depth of only 250 to 300 feet. However, the Dumbarton Point test hole penetrated to a depth of 433 feet without reaching bedrock. This apparent contradiction was resolved, when it became known that below 200 feet the drill encountered a sandy clay that became increasingly harder suggesting that it was probably an older formation underlying the alluvium.

Each test hole encountered at least two, and as many as five, aquifers. The remarkable consistency with which aquifers were encountered in the same depth intervals, plus the results of the Sparker survey confirmed the flat nature of the alluvial deposits beneath the marshland and south San Francisco Bay.

Electric Logging. At the completion of each test hole, an electric log was run by BZM Incorporated. Interpretation of the spontaneous potential and resistivity curves indicated the depths to aquifers missed by visual logging methods. The logs also indicated the relative salinity of ground water in these aquifers. From the electric logs, the total depth of influence of saline water intrusion was determined.

A combination of the geologic log and the electric log provided a clear picture of the subsurface conditions at the drill site and the means of planning the number, depth, and perforated interval of piezometers to be installed in the test hole.

Installation of Piezometers

In order to monitor the water level fluctuations and ground water quality in specific aquifers in the test holes, 24 two-inch diameter piezometers were installed at the ten drill sites.

The aquifers encountered during drilling were separated by extensive, thick clay layers, suggesting that each aquifer was hydrologically separate. The ideal situation would have been to install a piezometer opposite each aquifer. However, because of space limitations in the eight-inch diameter test holes, no more than three piezometers could be installed in any one hole. The necessity for drilling two test holes at Dumbarton Point permitted the installation of four piezometers at that location. The completed piezometer installation at the San Mateo Bridge site is shown in Figure 5. The construction details of all piezometers are shown in Table 5.

The piezometers consist of two-inch galvanized steel pipe perforated near the bottom, and installed in the test hole in such a way that each taps only a single aquifer. The separation between

TABLE 5

PIEZOMETERS INSTALLED IN THE SOUTH BAY TEST WELLS

PIEZOMETER NUMBER	LOCATION	DATE COMPLETED	ELEVATION OF CASING TOP IN FEET	TOTAL DEPTH IN FEET	PERFORATED INTERVAL IN FEET	DEPTH TO TOP AND BOTTOM OF MAIN AQUIFER IN FEET	DEPTH TO TOP AND BOTTOM OF GRAVEL PACK IN FEET	CASING DIAMETER IN INCHES	MAIN AQUIFER	TOTAL AQUIFER THICKNESS IN FEET
4S/3W- 7Q2	San Mateo Bridge	4/64	16*	157	Open Bottom	142-163	No Pack	6	Sand	21
4S/3W- 7Q3	San Mateo Bridge	4/64	16*	230	Open Bottom	212-272	No Pack	1	Sand	34
4S/3W- 7Q4	San Mateo Bridge	4/64	16*	399	378-399	361-416	No Pack	2	Sand	45
4S/3W-13B1	Alameda Creek	7/63	7.73	357	310-357	305-372	285-375	2	Sand and Gravel	35
4S/3W-13B2	Alameda Creek	7/63	7.84	189	156-189	153-186	139-191	2	Sand	28
4S/3W-13B3	Alameda Creek	7/63	7.71	63	43- 63	33- 70	34- 75	2	Sand	30
4S/3W-31B1	Radio Station KNBR	7/63	5*	390	340-390	339-387	No Pack	2	Sand and Gravel	22
4S/3W-31B2	Radio Station KNBR	7/63	5*	280	260-280	262-279	241-295	2	Sand and Gravel	17
4S/3W-31B3	Radio Station KNBR	7/63	5*	100	85-100	85- 96	69-105	2	Sand	11
5S/2W-14E1	Plummer Creek	4/64	6.2	83	63- 83	48- 78	44- 93	2	Sand	28
5S/2W-14E2	Plummer Creek	4/64	6.2	209	189-209	193-214	163-214	2	Gravel	21
5S/2W-14E3	Plummer Creek	5/64	6.6	294	274-294	280-300	255-295	2	Gravel	13
5S/2W-14E4	Plummer Creek	5/64	6.8	354	334-354	334-368	334-368	2	Sand and Gravel	28
5S/2W-17F2	Dumbarton Point	5/64	7.7	94	64- 94	63-120	61-140	2	Gravelly Sand	37
5S/2W-17F3	Dumbarton Point	5/64	7.8	215	195-215	199-235	173-231	2	Gravelly Sand	32
5S/2W-24B1	Mowry Slough	6/63	7.2	470	453-470	449-471	452-475	2	Sand and Gravel	22
5S/2W-24B2	Mowry Slough	6/63	7.8	220	190-220	188-215	170-253	2	Sand and Gravel	27
5S/2W-34N1	Mountain View Slough	6/64	7.0	84	77- 82	71- 80	64-105	2	Sand	11
5S/2W-34N2	Mountain View Slough	6/64	7.0	184	177-184	167-184	163-198	2	Sand	16
5S/2W-35R1	Moffett Field	7/63	7.2	280	190-280	180-210	No Pack	2	Gravelly Sand	30
5S/2W-35R2	Moffett Field	7/63	7.3	65	55- 65	54- 66	No Pack	2	Gravel	12
6S/1W- 5L1	Alviso Slough	6/64	7.0	84	74- 84	74- 85	62-102	2	Sand	11
6S/1W- 5L2	Alviso Slough	6/64	5.9	252	220-252	220-247	195-260	2	Sand and Gravel	26
6S/1W- 5L3	Alviso Slough	6/64	6.3	336	310-336	312-330	306-340	2	Gravelly Sand	18

* Approximate Elevation

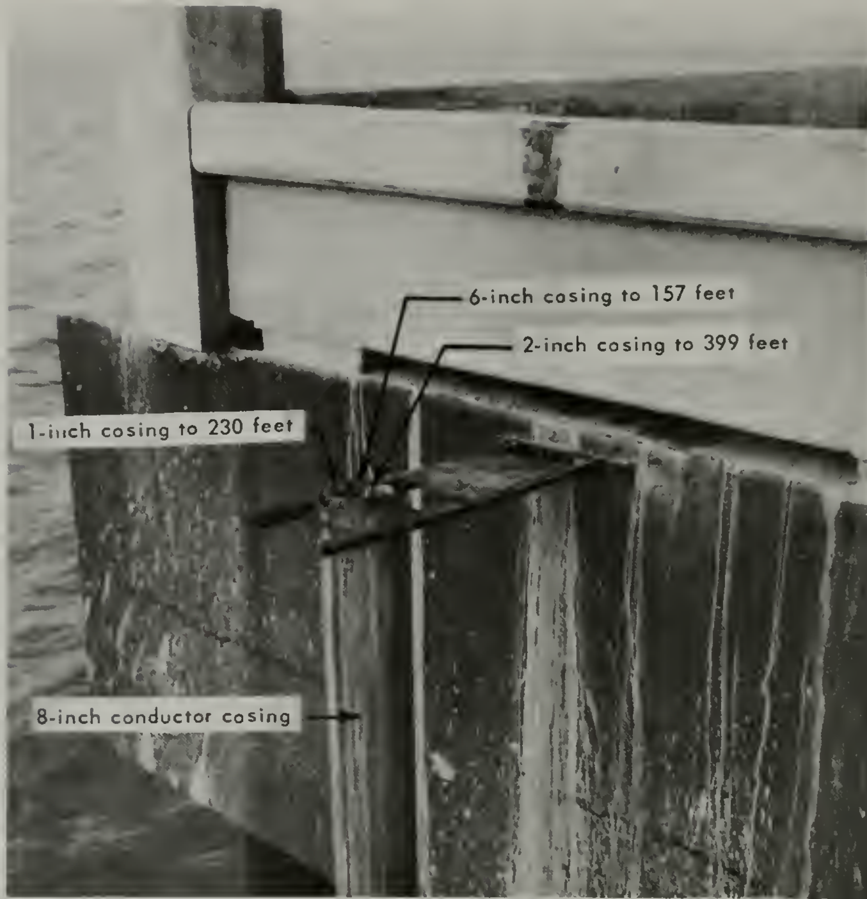
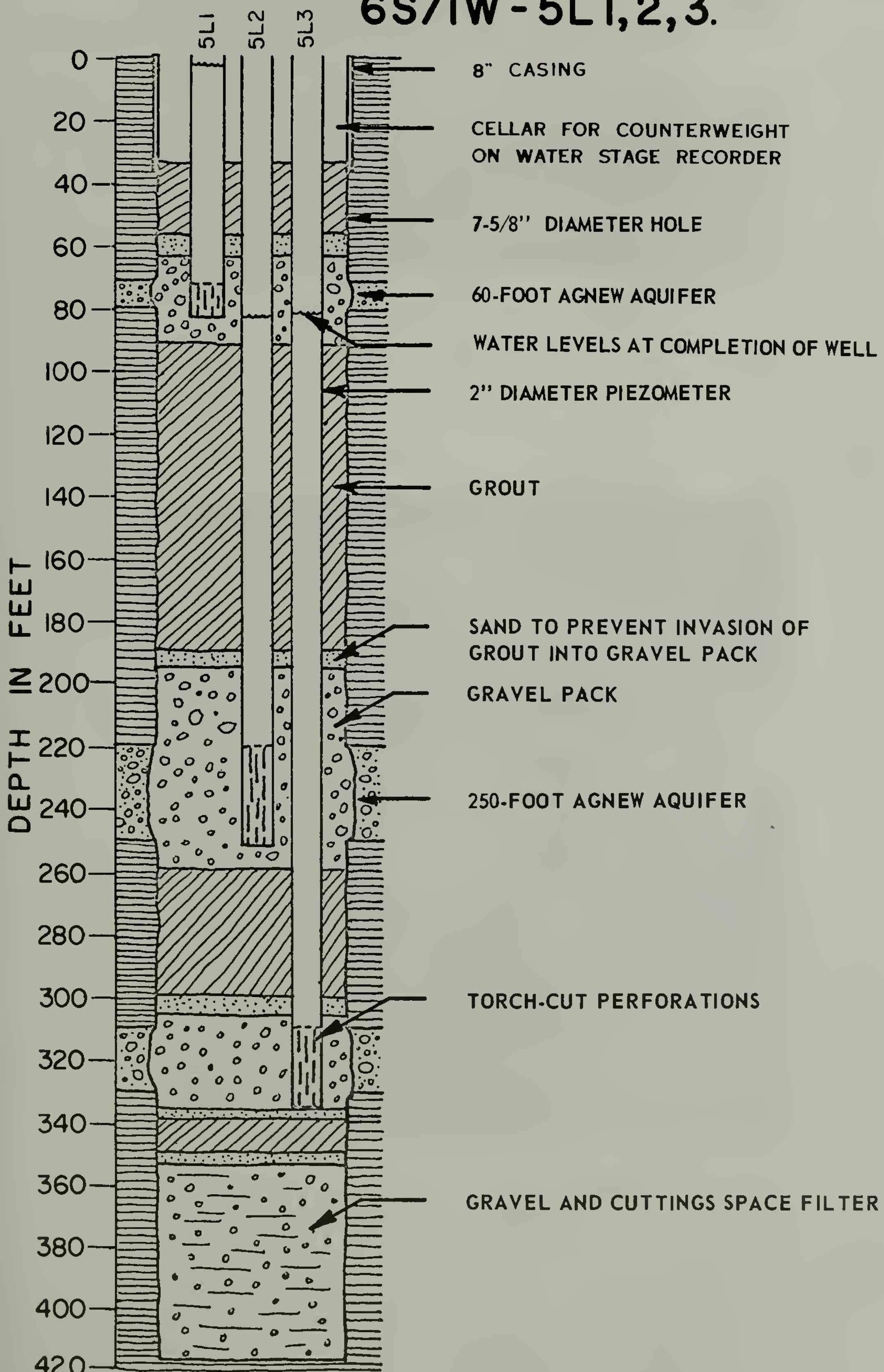


Figure 5. Completed test hole 4S/3W-7P, on San Mateo Bridge.

aquifers originally provided by thick clay layers is replaced in the hole by a grout plug located between the aquifers. A gravel pack is provided around each perforated section of pipe to allow movement of ground water into the piezometer. A cross-section of the finished installation at Alviso Slough is shown in Figure 6, which illustrates the typical construction methods used at all test hole sites.

Following completion of the installation, each piezometer was pumped until the flowing water was reasonably clear of suspended solids. This development process was accomplished by introducing compressed air through a 5/8-inch air hose positioned below the water

TYPICAL TEST WELL CONSTRUCTION METHOD SHOWN FOR THE ALVISO SLOUGH INSTALLATION 6S/1W-5L1,2,3.



surface. The piezometers were completed with the installation of a three-foot square concrete platform for the water level recorders. The platforms were inscribed with pertinent information so that each well could be properly identified in the future. An example of a typical test well site is shown in Figure 7. A water level recorder installed at a test well site is shown in Figure 8.

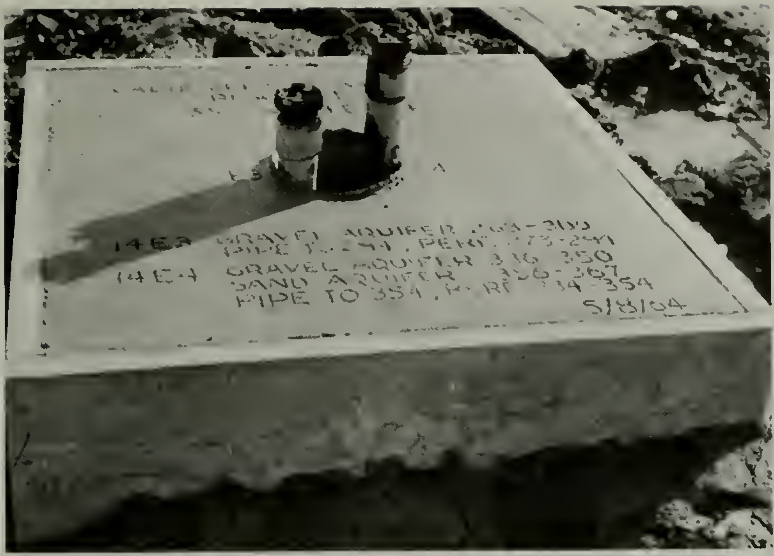


Figure 7. Completed test hole 5S/2W-14E, near Plummer Creek. Showing piezometers.

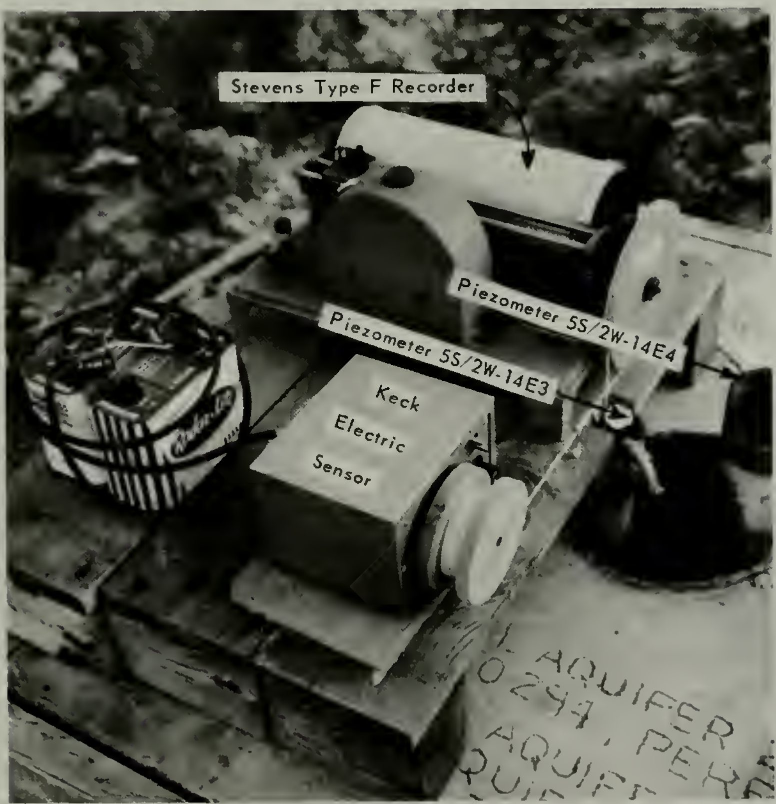


Figure 8. Water level recorder installation at piezometer 5S/2W-14E3.

CHAPTER VII. CHARACTERISTICS OF GROUND WATER AREAS

The South Bay Ground Water Basin has been divided into three main ground water areas based in part on physiography, geologic structure, lithology, and geohydrology. Each ground water area has been further subdivided into subareas based on the nature of the sediments and the nature and occurrence of ground water. The ground water areas and subareas are listed below and are discussed in some detail in this chapter.

Ground Water Area	Ground Water Subarea
Fremont	Niles Dry Creek Mission Warm Springs
Santa Clara	San Jose West Side Saratoga Berryessa Evergreen Santa Teresa Alamitos
San Mateo	San Francisquito Belmont

The ground water areas and their respective subareas are shown on Plate 11. The marked similarity between the boundaries of physiographic divisions, shown on Plate 2, and those of the ground water subareas, shown on Plate 11, reflects the geologic relationship between landforms and ground water.

Movement of ground water in the South Bay Ground Water Basin follows a fairly similar pattern from year to year. Recharge occurs at the edge of the basin along the many streams draining the highlands. Water infiltrates the streambeds and moves toward areas of maximum extraction, which are indicated by depressions in the piezometric surface. Because major extractions occur principally at municipal wells, which pump continuously, the main pumping depressions remain stationary from year to year.

Ground water cascades occur at several locations in the basin, particularly in the Santa Clara County portion. The cascades are formed both by movement of ground water through natural constrictions along its subsurface travel path and by movement along the upper surface of impermeable zones and thence into deep permeable materials. The ground water cascades are particularly noticeable whenever piezometric levels are lowered. The principal ground water cascades are located within the West Side subarea and along the boundary between the San Jose and Santa Teresa subareas. These ground water cascades are delineated on Plate 11.

There are many faults in the South Bay Ground Water Basin; however, only the Hayward fault is known to affect the movement of ground water. This fault is an effective barrier to ground water movement between the eastern and western portions of the Niles subarea and between the Mission and Warm Springs subareas.

Geologic structure, continuity of aquifers, nature of the alluvium, and occurrence and movement of ground water are discussed in detail below for each of the ground water areas.

Fremont Ground Water Area

The Fremont ground water area encompasses the eastern side of the South Bay Ground Water Basin north of the Alameda-Santa Clara

County line. The area is divided into the Niles, Dry Creek, Mission and Warm Springs subareas.

Niles Subarea

The Niles subarea is the largest ground water subarea in the Fremont ground water area. It includes not only the surficial extent of the Niles Cone, which is the alluvial fan formed by Alameda Creek, but extends southward and westward beneath San Francisco Bay and the Bay Plain. The areal extent of Niles subarea, shown on Plate 11, is based on the maximum limit of correlatable aquifers within it.

The Niles subarea is the most important ground water region in Alameda County and is second only to the San Jose subarea in importance within the South Bay Ground Water Basin. The eastern portions of the subarea are extremely permeable and yield large quantities of ground water to wells. The stratified and permeable nature of the alluvium within the subarea allows for rapid transport of ground water from the recharge area, at the eastern edge of the subarea, to points of withdrawal to the west.

Nature of the Alluvium. In general, the Niles subarea is composed of a series of flat-lying gravel aquifers separated by extensive clay aquicludes. Near the eastern extremity of the subarea, in the vicinity of Niles, the gravel portion constitutes nearly the total thickness of the alluvium. With increasing distance westward, both the thickness and grain size of the aquifers decreases while the intervening clay beds become thicker. This combination results in a westward reduction in the overall transmissive characteristics of the alluvium.

Another factor influencing the transmissive characteristics of the alluvium is the total thickness of the water-bearing sequence. Beneath that portion of the subarea east of Coyote Hills, bedrock forms a trough sloping to the southeast, as shown on Plate 3. Here, the water-bearing sequence ranges in thickness from less than 500 feet, on the north, to over 1,000 feet, on the south. In contrast, the depth to bedrock west of Coyote Hills is probably everywhere less than 500 feet.

Because of the characteristics of the alluvium, the most important portion of the Niles subarea lies generally east of a line between Coyote Hills and Alviso. The importance of this eastern portion can be readily seen by the grouping of high specific capacity contours on Plate 6. In contrast, it also can be seen that the portion of the subarea west of this Coyote Hills-Alviso line is not highly productive.

The extensive nature of the aquifers and aquicludes in the Niles subarea has made it possible to delineate specific aquifers and aquicludes and correlate them from one well to the next. The three uppermost aquifers were first named in Bulletin No. 81 [7/] and are, in order downward, the Newark, Centerville, and Fremont aquifers. Deeper aquifers recognized in Bulletin No. 81 are now known to be extensive, and are referred to in this report, according to their average depth as the "400-foot" and "500-foot" aquifers. Overlying the uppermost aquifer in an extensive aquiclude, named the Newark aquiclude, which is a significant feature with respect to downward movement of ground water into the underlying aquifers.

Newark Aquiclude. Nearly all of the Niles subarea is covered by a thick veneer of silt and clay called the Newark aquiclude. It is present east of the Hayward fault, an area usually pictured as being completely devoid of a clay cover. In general, the Newark aquiclude increases in thickness from the eastern edge of the subarea, where it is locally missing, westward toward San Francisco Bay. Variations in thickness of the aquiclude are shown in detail by the contours on Plate 12. This clay layer extends beyond the limits of the subarea, but because this outside portion is not directly related to ground water in the Niles subarea, contours are not shown beyond the subarea boundary.

Plate 12 shows two zones from which contours were omitted. One zone surrounds Coyote Hills and the second is about two miles to the southeast. The Newark aquiclude probably exists in these areas, but because the underlying Newark aquifer is missing, the clay is much thicker and extends downward to merge with the clay layer overlying the deeper Centerville aquifer.

Variations in thickness of the Newark aquiclude are significant. Because this layer generally has a low permeability, thicker portions prevent widespread infiltration of surface water into the underlying Newark aquifer. Without these thicker zones, salt water in the bay could move into the underlying aquifers relatively unimpeded. Thinner portions of the aquiclude are slightly more pervious to the downward movement of water. This has permitted saline water to intrude certain parts of the Newark aquifer.

If the Newark aquiclude were not thin or missing immediately west of the Hayward fault, recharge from Alameda Creek could not occur there. This recharge area, shown on Plate 12, extends about 2½ miles westerly from the crossing of the Western Pacific Railroad and the Hayward fault. Here only a sinuous strip of the Newark aquiclude is present, suggesting that the remainder has been eroded away by an ancestral Alameda Creek.

The present channel of Alameda Creek passes north of the recharge area. It has cut nearly through the Newark aquiclude and portions of the channel area in the two-mile reach downstream from the Hayward fault are now in direct contact with the underlying Newark aquifer.

Newark Aquifer. The Newark aquifer, lying directly beneath the Newark aquiclude, was first named in Bulletin No. 81 7/ for the extensive gravel layer present east of Coyote Hills between 60 and 140 feet beneath the ground surface. This aquifer is now known to be an extensive, flat gravel layer underlying almost the entire Niles subarea, as shown on Plate 5. It is missing only in a few spots which are shown on Plate 13.

Nearly all well logs in the Niles subarea indicate the presence of the Newark aquifer. Particularly good control is provided by the numerous well logs along Dumbarton Bridge. On the western side of the bay, control is provided by the logs of the Ravenswood wells, which show that the aquifer continues beneath the marsh both north and south of the western end of Dumbarton Bridge.

The Newark aquifer is the main conductor of salt water eastward from San Francisco Bay. This eastward migration of salt water indicates that the Newark aquifer is fairly continuous throughout the Niles subarea.

The depositional pattern in the Niles subarea is shown on Plate 13 by lines of equal thickness of aquifers within the upper 170 feet. A depth of 170 feet was chosen because this depth includes all of the Newark aquifer but excludes aquifers beneath it. Thus, the thickness contours shown on Plate 13 generally represent the thickness of the Newark aquifer. The thickness of the aquifer ranges from over 140 feet at the Hayward fault to less than 20 feet at the western edge of the subarea. Those portions of the subarea in which aquifers are particulary thick probably represent zones where streams continuously deposited coarse material; these zones are shown on Plate 13 by heavy lines with arrows. The zones of major aquifer deposition extend to the bay around the north and south ends of Coyote Hills.

No contours of equal thickness of water-bearing materials are shown for the area east of the Hayward fault because no specific aquifer has been defined there. The alluvium there is nearly all gravel and is very permeable and open; it provides very high yields of ground water to wells. Wells do not penetrate much below a depth of 200 feet, because sufficient water can usually be obtained in this short depth.

Plate 4 indicates that the deepest well east of the Hayward fault is 225 feet in depth. Furthermore, two wells less than 200 feet in depth encountered bedrock. Because of this anomaly, the exact depth of the alluvium is not known precisely, but probably does not exceed 300 feet anywhere in this area.

The permeability of the water-bearing sediments east of the fault decreases to the southeast. The Santa Clara Formation, exposed in the Mission subarea, probably underlies the southern portion of this area and is concealed thinly by alluvium. Logs of the few wells in this southern portion show a lack of aquifers between the ground surface and a depth of 170 feet.

The alluvium immediately east of the fault is extremely permeable, and ground water within this area is largely unconfined. When recharge occurs from Alameda Creek, water levels rise rapidly and nearly equally over all the area; conversely, when pumping occurs, the levels fall equally. This is caused by the very high transmissive characteristics of the alluvium. Alameda Creek represents the only major source of surface recharge to the alluvium east of the fault; some underflow may occur from the Santa Clara Formation. Because the permeability of the alluvium is high, the contribution that is probably derived from the adjacent Mission subarea is not detectable in wells in the area. However, water levels are higher in the Mission subarea; therefore, a gradient toward the alluvium of the Niles subarea exists.

Centerville Aquifer. The next most important aquifer beneath the Newark aquifer was named the Centerville aquifer in Bulletin No. 81.[7/] This aquifer covers nearly as much of the Niles subarea as the overlying Newark aquifer. It is present nearly everywhere, except in the depositional shadow west of Coyote Hills, as shown on Plate 14. The Centerville aquifer lies at an average depth of between 180 and 200 feet below ground surface and is often referred to as the "180-foot" aquifer. The areal extent of the aquifer is delineated on Plate 14; it ranges in thickness from 10 to 100 feet.

An extensive thick clay aquiclude separates the Newark aquifer from the underlying Centerville aquifer and largely protects the lower aquifer from saline water contained in the Newark aquifer. Well 5S/2W-21L1, in the center of the South Bay, taps the Centerville aquifer and produces reasonably good quality water, in spite of the fact that the overlying Newark aquifer has contained saline water for a number of years. This is good evidence that the intervening aquiclude is impermeable even though a considerable head differential exists between the Newark aquifer and the Centerville aquifer.

The aquiclude separating the Newark and Centerville aquifers is thickest beneath San Francisco Bay. It thins to the east as the adjacent aquifers become thicker. Well log data suggests that several thin zones in the aquiclude exist west of Coyote Hills. These may allow some downward movement of saline water from the Newark aquifer into the Centerville aquifer.

The Centerville aquifer extends beneath San Francisco Bay as a flat lying gravelly sand layer. The aquifer is the main ground water producer for wells located on the marsh along the western side of the bay and those located near Dumbarton Strait. Wells in the Ravenswood field tap this aquifer, as do older wells drilled in the South Bay for the Morgan Oyster Company.

Some ground water probably moves through the Centerville aquifer and into the San Jose area. This feature is discussed in a later section of this chapter.

Fremont Aquifer. The Fremont aquifer is separated from the overlying Centerville aquifer by a thick extensive clay aquiclude. The Fremont aquifer is not as well defined as the Newark and Centerville aquifers but is generally thicker and more productive. The Fremont aquifer also has a different areal shape than the two upper aquifers, and well logs imply that it exists primarily in that portion of the Niles subarea east of Coyote Hills. The depth to the Fremont aquifer varies from 300 to 390 feet below ground surface. The aquifer merges with the overlying aquifers near the Hayward fault.

Ground water levels in aquifers more than 170 feet below ground surface do not have sufficient differences in head to be separated into individual units. For this reason, these deeper aquifers have been combined into one water-bearing zone. The thickness of aquifers in the interval from 170 feet to 400 feet below ground surface is shown by lines of equal thickness on Plate 14. This plate does not include aquifers which are deeper than 400 feet because well log data below this depth are incomplete. The broad lines on Plate 14 indicate the axes of major aquifer deposition, which were the locations of the more persistent streams during the accumulation of the alluvial sediments of this depth interval. This interval is the most productive portion of the Niles subarea and is the source of most of the ground water pumped.

Deeper Aquifers. Wells reaching depths greater than 400 feet are scattered throughout the Niles subarea, suggesting that highly productive aquifers may be found at depths below 400 feet. Where wells are close together, these deep aquifers can be correlated for short distances, as shown on Plate 5. These correlatable portions of the aquifers suggest that they are relatively flat lying. Hydrologic conditions in these deeper layers can generally be determined from the water levels in deep wells. The aquifers below 400 feet, called the "400-foot" and "500-foot" aquifers, may extend beyond the limits in the Niles subarea and thus act as conductive layers for the migration of ground water out of the Niles subarea. The configuration of water levels in wells tapping the deeper aquifers shows a gradient toward the north. This suggests that ground water moves toward the north beneath the boundary between the Niles subarea and the adjacent San Leandro Cone. It apparently moves toward the pumping depression caused by the deep municipal wells in Hayward. The deeper aquifers appear to be recharged near the eastern edge of the Niles subarea by direct infiltration of water from Alameda Creek.

The origin of the deeper aquifers is open to speculation. One explanation is that the alluvial fan of Alameda Creek is superimposed upon older formations (the deeper aquifers) whose origins are different. A second explanation is that this lower portion is an older alluvial fan, deposited by Alameda Creek prior to fairly recent horizontal movement along the Hayward fault. This movement has since shifted this older portion of the fan northward into a position halfway between the San Leandro Cone and the present location of the Alameda Creek alluvial fan.

The extent of the deeper aquifers is important because, if the Niles subarea became degraded by salt water to considerable depths, the outward movement of ground water might also degrade the quality of water in adjacent deeper areas. Thus, since some communities north of the Niles subarea use ground water from these deeper aquifers, any sea water intrusion into the Niles subarea could migrate toward pumping depressions and consequently degrade ground water in these latter areas.

The Coyote Hills barrier and the relatively shallow bedrock to the west have been important in the depositional history of sediments along the western portion of the Niles subarea. Because of this barrier, streams were unable to deposit appreciable thicknesses of permeable materials. As bedrock adjacent to Coyote Hills is at a depth of less than 500 feet, it is reasonable to assume that sediments east of Coyote Hills below 500 feet could be correlative to the Santa Clara Formation.

The profile along the alignment of the San Mateo Bridge shown on Plate 5, shows a thick aquifer between depths of 400 and 550 feet. This aquifer is composed almost entirely of sand and contains ground water of good quality. The aquifer is undoubtedly a part of the extensive sand deposits which underlie the bay north of the area of investigation. In fact, it may be part of the Alameda Formation reported by Trask and Rolston 34/ to be present as far north as the San Francisco-Oakland Bay Bridge.

It appears likely that that portion of the valley floor in the vicinity of the San Mateo Bridge was a boundary zone between alluvium deposited primarily under subareal conditions to the south, and sediments primarily of marine origin to the north. Because of a lack of well data beneath the bay at the northern end of the area of investigation, the exact relationship between these areas of subareal and marine deposition is not clearly known. In aquifers beneath the main portion of the bay, ground water may move southward toward the Niles subarea, in response to lowered water levels. The coarser sediments within the Niles subarea, and those beneath the bay north of the San Mateo Bridge, are known to be lithologically similar. However, there is a difference of grain size; aquifers of the Niles subarea are generally composed of coarse sand and gravel, while those beneath the bay are composed of well sorted sand.

Continuity of Aquifers. Nearly all logs of water wells located in the western portion of the Niles subarea show that the aquifers are flat-lying and separted by extensive clay layers.

Numerous geologic profiles across the bay, particulary the one across Dumbarton Strait, show that these aquifers can be correlated westward beneath San Francisco Bay to San Mateo County.

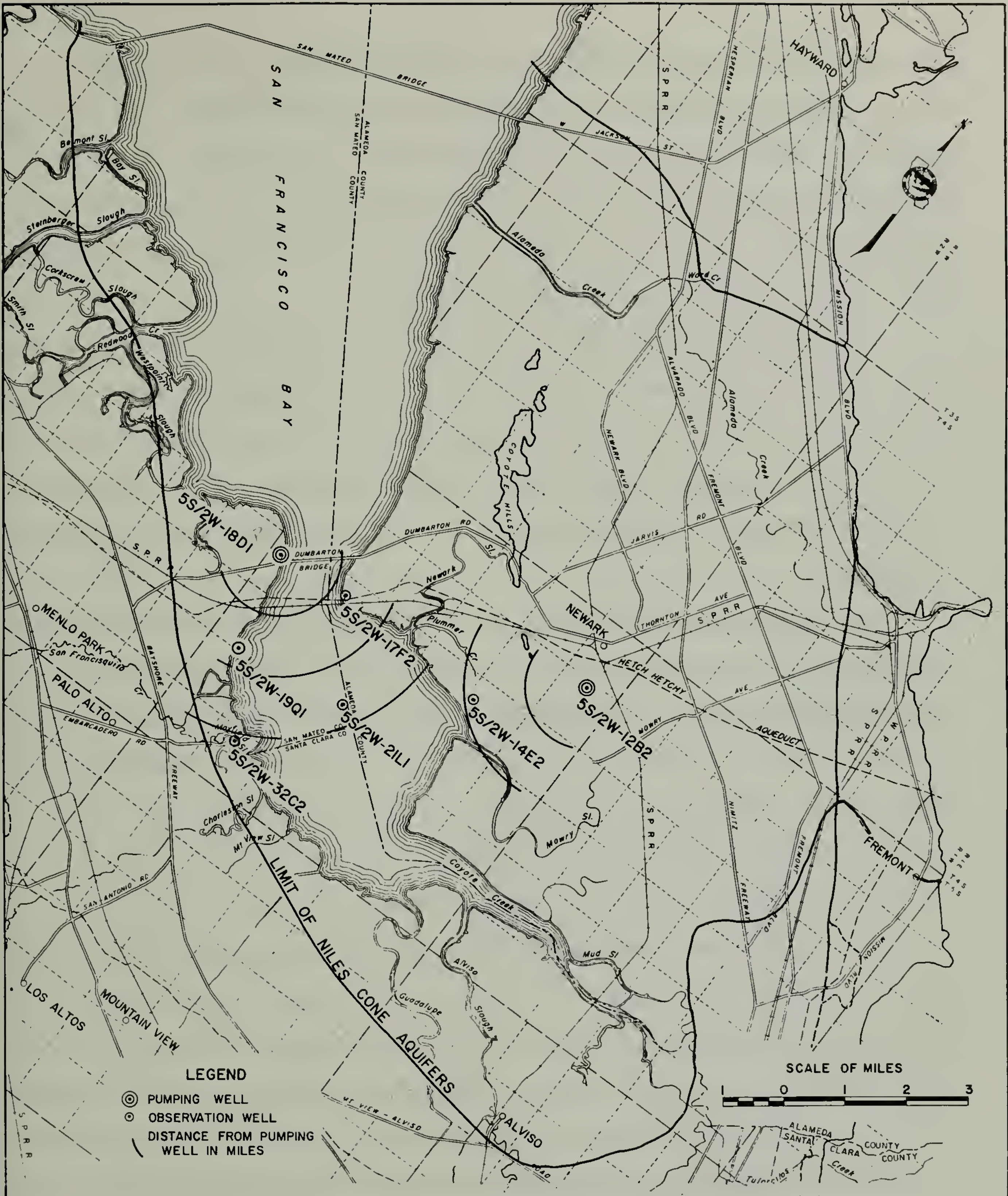
In order to prove these correlations, several aquifer continuity tests were performed during this investigation. For these tests, wells located at the west end of Dumbarton Bridge which were known to draw their water supply from the Centerville aquifer were pumped. The effects of pumping were observed in six distant wells known to tap the same aquifer.

The first test was performed in April 1963, when wells 5S/2W-18D1 and 5S/2W-18E3 were pumped continuously for eight days at a combined rate of 580 gallons per minute. During this period, a continuous record was obtained of the water level fluctuations in each of five observation wells. The location of pumping wells and observation wells is shown in Figure 9. A drawdown was observed in three of the five wells as shown in Table 6.

Table 6
AQUIFER CONTINUITY PUMP TEST
WEST END OF DUMBARTON BRIDGE

Observation Well Number	Distance to Pumping Wells 5S/2W-18D1 and 5S/2W-18E3	Magnitude of Drawdown
5S/2W-18E2	140 feet	17 feet
5S/2W-21L1	13,800 feet	3.0 feet
5S/2W-32C2	16,600 feet	1.3 feet
5S/2W- 9E1	21,600 feet	0 feet
5S/2W-10Q5	34,800 feet	0 feet

After completion of test well 5S/2W-17F2 at Dumbarton Point, it was possible to test the continuity of the Centerville aquifer across Dumbarton Strait. Well 5S/2W-18D1 again was pumped and a drawdown was observed in well 5S/2W-17F2, thus proving the continuity of the Centerville aquifer eastward around the Coyote Hills barrier.



LOCATION OF WELLS USED TO DETERMINE THE CONTINUITY OF A NILES CONE AQUIFER

This test was designed primarily to obtain aquifer coefficients in well 5S/2W-12B2, located at the Leslie Salt Company plant. During pumping of this well, a very slight drawdown was observed in well 5S/2W-14E2, located 10,500 feet to the southwest. This aquifer continuity test showed that the Centerville aquifer is continuous beneath this portion of San Francisco Bay.

The continuity tests performed on the Centerville aquifer suggest that other equally correlatable aquifers beneath San Francisco Bay may also belong to the Niles subarea aquifer system. Furthermore, the tests show that correlation of aquifers between wells appears to be valid over long distances within the area influenced by the bay environment.

Boundary Conditions, Northern Extremity. The Niles subarea is bounded on the north by the San Leandro Cone, which contains a water-bearing sequence that ranges in thickness from about 400 feet at the hillfront to as much as 1,000 feet beneath the Bay Plain. The cone includes all of the area underlain by the alluvial fan of San Leandro Creek as well as portions of the Bay Plain underlain by alluvial materials derived from this creek.

In general, sediments in the San Leandro cone are of fairly low permeability, as suggested by the low values of the specific capacity contours shown on Plate 6. Specific capacities of wells in the area usually do not exceed 20 gallons per minute per foot of drawdown. In spite of this apparent low permeability, a few deep wells are highly productive. A maximum of 955 gallons per minute was developed at a well in the southeastern portion of the cone.

The San Leandro cone is divided into an upper and lower zone. The upper zone includes the water-bearing sequence to a depth of 400 feet. The alluvium in the upper zone contains two main aquifers, each consisting of discontinuous beds of fine gravel which are not easily correlated on well logs. The upper aquifer is at a depth of about 60 feet and is equivalent to the Newark aquifer in the Niles subarea. The lower aquifer is at a depth of about 250 feet and is equivalent to the Centerville aquifer. The two aquifers in the San Leandro cone are separated from their counterparts in the Niles subarea by fine-grained zones.

The grain size distribution in this cone is similar to that in other alluvial cones in that the percentage of gravel increases toward the apex of the cone. The total thickness of gravel in the upper zone ranges from a maximum of 112 feet at the apex, to less than 40 feet near the northwestern edge of the cone. These thicknesses represent a range in aquifer percentage in the upper zone of from 25 percent near the apex, to less than 10 percent, near the distal edge of the cone.

Because the alluvium in the upper zone becomes fine-grained near the distal edge of the cone, a ground water condition exists that is largely independent of adjacent areas, with the result that little lateral movement of ground water occurs into or out of the cone in this upper cone.

The lower zone, which occurs below a depth of 400 feet, contains considerably more aquifers than the upper zone and nearly all of the high yielding wells draw their supply from it. Well logs show that usually over 30 percent of the lower zone consists of sand and gravel, a percentage that is three times as large as that in the upper zone.

The thickness of aquifers in the lower zone does not materially decrease near the edge of the cone. This information together with the configuration of water levels in wells tapping this zone, suggests that the origin of the lower zone may be totally unrelated to that of the upper zone.

Shallow unconfined ground water occurs near the hillfront in a small area overlying the boundary between the San Leandro cone and the Niles subarea. This shallow aquifer overlies the Newark aquiclude in the Niles subarea and its equivalent in the San Leandro cone. Only a few domestic wells tap this aquifer, and they are generally less than 50 feet in depth.

Ground water is confined in all other aquifers in the San Leandro cone. Within the upper zone, aquifers to a depth of 200 feet have a pressure head that always stands above sea level in the upper reaches of the cone. Contours of equal elevation of ground water in wells tapping this interval are characteristically fan shaped, indicating that recharge occurs at the apex of the cone from infiltration along San Leandro Creek.

A small amount of ground water may move from aquifers in the upper 200 feet of the San Leandro cone southward into the Newark aquifer of the Niles subarea. This is suggested by ground water contours which slope southward with the same configuration from year to year. The fine-grained nature of the alluvium beneath the common boundary indicates that the amount of ground water movement must be small.

Under the present pattern of pumping water levels in wells tapping aquifers below 200 feet stand below sea level during most of the year. Well logs, water level measurements, and chemical analyses suggest that there is little or no interchange of ground water between aquifers above 200 feet and those below 200 feet.

Investigators of ground water conditions in the San Leandro cone have long held that aquifers in the lower zone are replenished by deep aquifers in the Niles subarea. The investigation leading up to Bulletin No. 81 [7/] tended to support this view and further suggested that some replenishment of these deep aquifers also occurs from the lowermost portions of the San Leandro Cone.

Because water levels in the upper portion of the cone tend to remain above sea level throughout the year, only a few shallow wells near the southeastern edge of the cone show any evidence of salt water intrusion from San Francisco Bay. The draft on aquifers in the upper 200 feet of the cone has not been sufficient to lower water levels to a point where salt water could intrude into the permeable area at the apex of San Leandro cone and thence move downward to greater depths. Deeper aquifers are protected from salt water intrusion from San Francisco Bay because of the high clay content in the overlying alluvium, even though the pressure head in these aquifers is considerably below sea level.

<u>Boundary Conditions, Southwestern Extremity</u>. The piezometric surface of ground water in the Newark aquifer slopes toward the south and west. The gradient is steep in that portion east of the bay, it flattens beneath the bay, and then apparently becomes steep again in the vicinity of Alviso. This gradient shows that the potential direction of ground water movement is from the Niles subarea toward the pumping

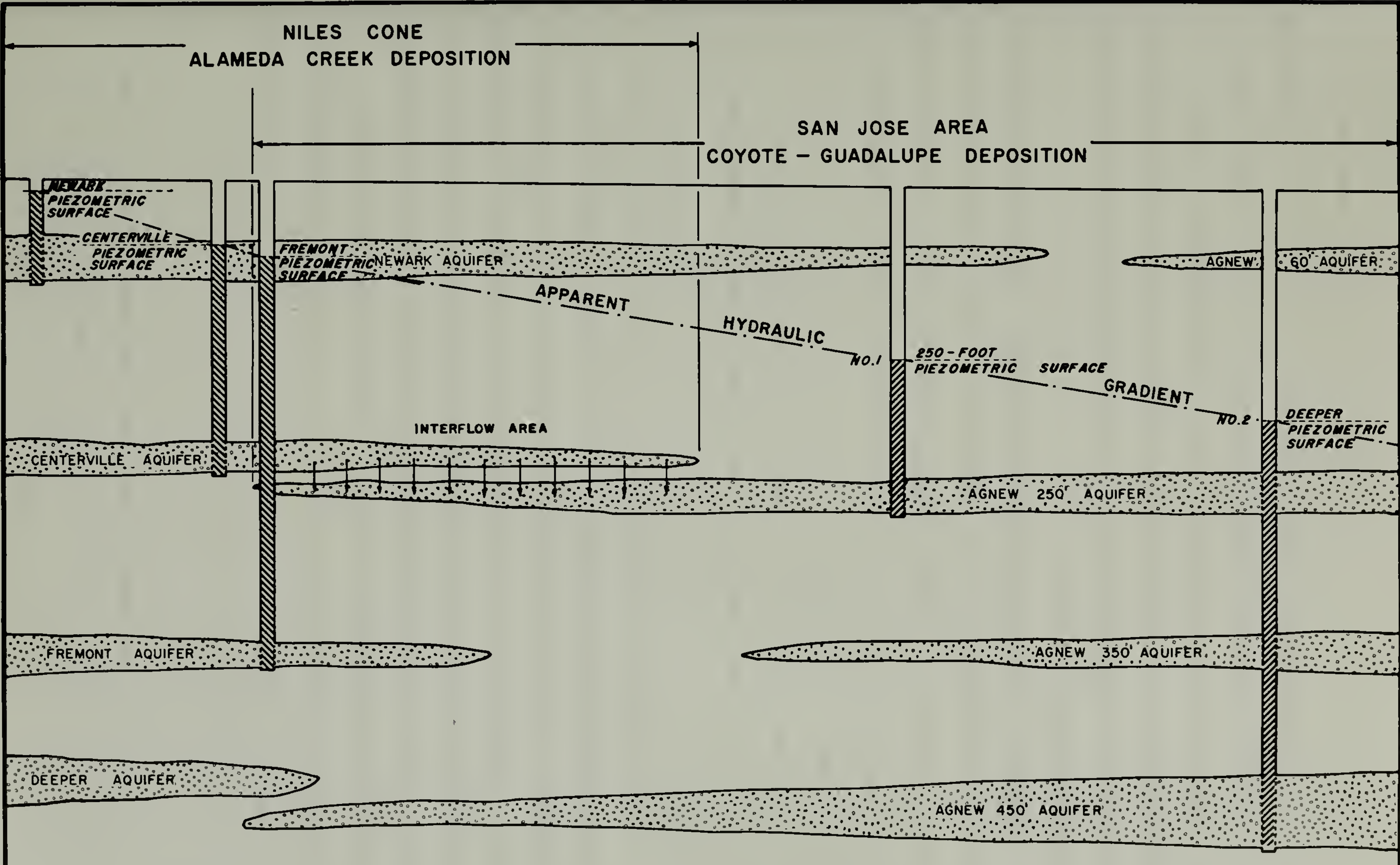
depressions near San Jose. However, in view of the low permeability the quantity of water actually moving must be quite small. Evidence from well logs supports this view.

The continuous aquifers within the Niles subarea become thin and fine-grained toward the southwest. In a similar fashion, aquifers in the San Jose subarea become thin and fine-grained from south to north. Consequently, the boundary between the Niles and the San Jose subarea is a clay-rich zone in which the sediments from both subareas interfinger. Only occasionally are aquifers from the two subareas in close proximity so that ground water can move from one subarea into the other. Wherever this is the case, the permeability of the sediments is so low that only small quantities of water actually move across the interface. This condition is illustrated diagramatically in Figure 10, which is based on a well log profile through Alviso.

The two principal aquifers between which a transfer of ground water takes place are the Centerville aquifer in the Niles subarea, and the 250-foot Agnew aquifer in the San Jose subarea. As shown in Figure 10, the higher piezometric head in the Centerville aquifer tends to move water through the dividing clay zone and into the lower pressure 250-foot Agnew aquifer. The ground water gradients illustrated in Figure 9 have been observed in previous investigations in this area. However, prior to the present investigation, their true significance was not recognized.

Boundary Conditions, Western Extremity. The Newark aquifer in the Niles subarea is the main conductor of saline water from San Francisco Bay eastward. Well logs in the San Francisquito

FIGURE 10



DIAGRAMMATIC PROFILE SHOWING RELATIONSHIP OF NILES CONE AQUIFERS TO AGNEW AQUIFERS subarea show an aquifer at a depth of 60 feet below ground surface that may correlate with the Newark aquifer. On the basis of these data, the two aquifers may be interconnected. If any ground water is contributed from this aquifer to the Newark aquifer, it must be quite small since the Newark aquifer is fairly thin, fine-grained, and somewhat discontinuous near the boundary between the Niles and San Francisquito subareas.

Barrier Effect of the Hayward Fault. The Hayward fault creates a partial barrier to the westward movement of ground water in the Niles subarea. For many years, this fact has been recognized because the barrier causes a sharp drop in water levels in wells from east to west. A maximum observed difference of 70 feet was reported in Bulletin No. 13.[8/] The difference in water levels creates the driving head which forces ground water through the fault barrier.

During this investigation, a difference of water levels of 64 feet was observed between wells 4S/1W-28B2 and 4S/1W-28C3. At the same time, wells 4S/1W-34L1 and 4S/1W-34K2 showed a difference of 73 feet. However, this is not considered a maximum for these two wells, since a 97 foot difference was recorded between them on October 21, 1958. The difference in water levels across the fault is not constant throughout the year. This is shown by monthly measurements taken during 1950 at wells 4S/1W-28B1 and 4S/1W-28C2. The measurements showed that the maximum difference occurs during the latter part of October and gradually diminishes to a minimum in February.

Because of the lenticular nature of the alluvium in the Niles subarea west of the Hayward fault two sets of water levels exist: an upper level and a deeper level. If this condition extended eastward to the fault zone, two water level differentials could be measured across the fault by the use of a shallow well and a deep well west of the fault and a single well east of the fault. Water level hydrographs from deep and shallow wells located just west of the fault show no significant difference in water levels. As a result, the true differential across the fault can be determined by measuring the water levels in any of the wells located near the fault zone. This is hydrologically significant. Water level contour maps show that the two sets of water levels merge just west of the Hayward fault. This indicates that ground water moves downward into the deeper aquifers in a forebay area located west of the fault.

Tidal Loading. The rhythmic fluctuation of tides in San Francisco Bay imposes a constantly changing load on the confined aquifers underlying the bay. These confined aquifers are elastic and compressible, and water levels in wells tapping them move up and down in response to the tides. The greatest response to tidal loading occurs in aquifers directly beneath the bay. Response quickly decreases with increasing distance from the bay. A tidal efficiency of 93 percent, the highest observed, was measured on the hydrograph of well 5S/2W-21L1, located near the center of San Francisco Bay, south of Dumbarton Bridge. A tidal efficiency of 93 percent means that the amplitude of water level fluctuations in the well is within seven percent of duplicating the tidal amplitude.

Some aquifers near San Francisco Bay are extremely sensitive to tidal loading. An example of this is the hydrograph of test well 4S/3W-13B1 which responded to tsunamis (seismic sea waves) generated by the Alaskan earthquake of April 27, 1964. The effect of the tsunamis were recorded as sharp peaks on the hydrograph during low tide. These peaks, seven in number, occurred at the identical time that nearby tide gauges recorded the arrival of the tsunamis, which were all less than five inches in height. The remarkable thing at the test well was that the slight change in overburden pressure caused by a passing wave only a few inches in height affected an aquifer over 285 feet below the ground surface.

Tidal loading has been recorded to some extent on hydrographs of all test wells near San Francisco Bay. Farther inland, only a few hydrographs indicated any tidal loading. West [35] reported that tidal loading was observed in wells in the Alvarado well field. He further stated that this was the easternmost observation of tidal loading.

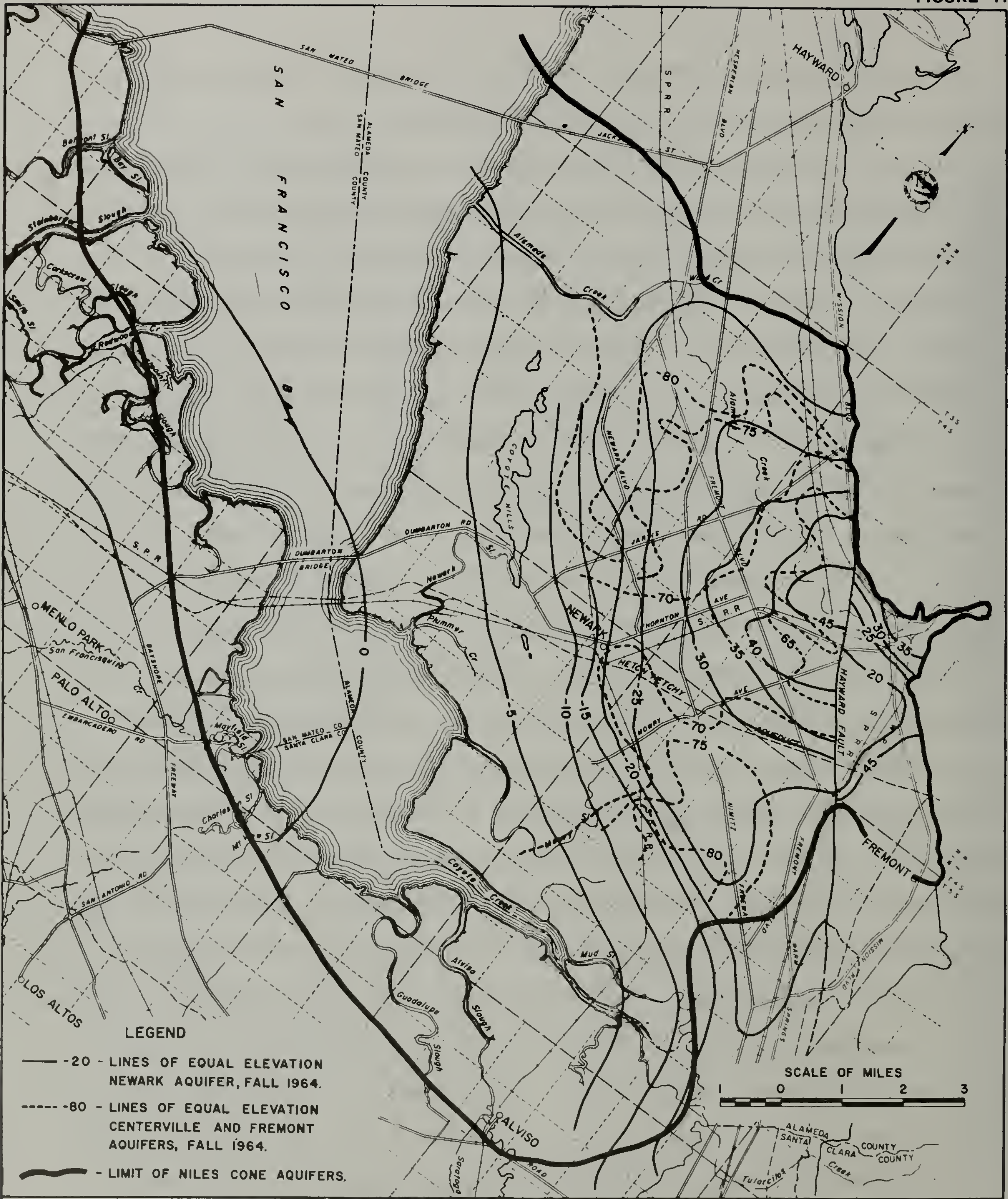
For several years, the U.S. Geological Survey has obtained continuous hydrographs from wells in San Jose that indicate tidal loading there. However, interference from nearby pumping wells largely masks the record so that positive proof of tidal loading at this distance from the bay cannot be accurately determined. A response to tidal loading at this distance would substantiate the theory that there is a continuity of aquifers extending from the bay to San Jose. The correlation of the 250-foot Agnew aquifer between Alviso and the area northeast of San Jose shows that this theory is well founded. Well logs indicate that the 250-foot Agnew aquifer is permeable and confined and would be capable of transmitting the effects of tidal loading.

<u>Mechanism of Saline Water Intrusion</u>. Intrusion of saline water in the Newark aquifer from the vicinity of San Francisco Bay eastward into the Niles subarea has been observed for some time.

The saline water-fresh water interface has moved steadily eastward until it finally reached the Hayward fault.

The hydraulic situation allowing intrusion is illustrated by ground water contours of the Newark aquifer and a composite of contours of deeper aquifer, as shown in Figure 11. The main difference between the two sets of contours is that the hydraulic gradient for the Newark aquifer slopes eastward while that of the deeper aquifers slopes westward. The clay aquiclude separating the Newark aquifer from the deeper aquifers is missing in the area immediately west of the Hayward fault. This allows for downward percolation of degraded ground water into the deeper aquifers.

These ground water conditions have been created by the magnitude and pattern of pumping during the last few decades. Heavy pumping from the Centerville and deeper aquifers has created a trough in the area east of Coyote Hills. Because these aquifers are recharged only at the eastern edge of the subarea, ground water moves westward toward the depression in response to the established gradient, and the piezometric surface near the recharge area is lowered. This lowered surface creates an eastward gradient in the overlying degraded Newark aquifer, which allows saline water to move toward the forebay. As the saline water approaches the forebay, it moves downward through thin spots in the underlying aquiclude and into the next aquifer below. Furthermore, on reaching the forebay area, this saline water may cascade over the eastern edge of the clay layer and move into the deeper aquifers. The deeper aquifers then conduct the saline water westward toward the pumping trough. In addition, some saline water from the Newark aquifer may also reach deeper aquifers through imperfectly constructed or improperly abandoned water wells.



GROUND WATER CONTOURS

NILES CONE

Two separate sources exist for the saline water found in the Newark aquifer: saline water in San Francisco Bay and saline water from salt evaporation ponds surrounding the bay. In order to enter the Newark aquifer, salt water from either San Francisco Bay or the salt ponds must first percolate through the Newark aquiclude. Thin zones in the aquiclude provide such percolation avenues. For this reason, the ship channel through Dumbarton Strait, in which the Newark aquiclude is often less than 20 feet thick, has long been suspected as a principal avenue for entrance of salt water into the Newark aquifer. Plate 12 shows that other areas are thin also and some of these thin areas underlie salt ponds.

The total area covered by the salt ponds is shown on Plate 12. The function of the salt evaporation ponds is to evaporate the bay water to a level of supersaturation so that sodium chloride will precipitate out of solution. Consequently, at the final stage of evaporation, the ponds contain a highly concentrated solution of sodium chloride. Those ponds closest to the salt processing plant at the south end of Coyote Hills are at final evaporation stage and thus most highly concentrated. This is because the salt solution is moved closer to the plant as it becomes saturated through evaporation.

The salinity of the salt solution in the ponds is many times higher than that of bay water. Hence, only a relatively small quantity of highly saline solution influences the salinity of ground water in the Newark aquifer to a greater degree than an equal quantity of less saline bay water.

Another reason salty bay water may move through the Newark aquiclude is because of the hydraulic differential existing between the water in the bay and that in the Newark aquifer. The quantity of bay water moving through the clay may be substantial even though the permeability of the clay is low. This is because a large area of the Newark aquiclude is in direct contact with the water in the bay.

Dry Creek Subarea

The Dry Creek subarea is superimposed on a portion of the Niles subarea. It is located just south of the divide between the San Leandro cone and Niles subarea and is the smallest ground water subarea within the basin.

The alluvial fan of Dry Creek was formed as a rather late development in the depositional history of the eastern side of the basin. It overlies deposits of the Niles subarea. Alluvium that is a part of the Dry Creek alluvial fan extends southwest from the hillfront a distance of about three miles; it has a maximum thickness of about 350 feet.

A profile of the Dry Creek subarea is shown on Section A-A' on Plate 5. This profile shows that the sand and fine gravel aquifers in the Dry Creek subarea are thin and discontinuous and that most of the subarea consists of clay. The number and thickness of individual aquifers, and consequently the transmissibility, increases toward the point where Dry Creek emerges from the hillfront.

Ground water in the Dry Creek subarea is largely confined by thick extensive clay layers overlying and separating the individual aquifers. Water levels are usually high and recharge occurs at the eastern edge through infiltration from Dry Creek.

Well logs show that aquifers become thicker toward the southern portion of the Dry Creek subarea suggesting that well production should be higher there. One well, reported to be approximately 248 feet deep, produced 700 gallons per minute and had a specific capacity of over 100. Such a high yield is not typical for the Dry Creek subarea.

Mission Subarea

The Mission subarea includes all exposed portions of the Santa Clara Formation within the Mission Upland physiographic unit and also a small area where a thin cover of alluvium overlies the Santa Clara Formation just east of the Hayward fault. The thickness of the Santa Clara Formation in this subarea may exceed 500 feet; however, the deepest well penetrates only 298 feet of the formation.

Most water wells in this subarea are located in the northern portion. Yields here are between 200 and 400 gallons per minute. Well logs indicate that the upper 100 feet of materials contain over 50 percent gravel. Below 100 feet, even larger gravel percentages are recorded. For example, the log of a well 298 feet in depth shows 68 percent gravel in the interval below 200 feet in depth.

The Santa Clara Formation dips easterly at less than 30 degrees. Consequently, while the overall permeability of the formation may be fairly high, the combination of stratification and eastward dip precludes any significant westward movement of ground water. The Hayward fault also acts as a barrier to the westward movement of ground water. Because of these two features it is unlikely that any significant quantities of ground water move from this subarea into the adjacent Warm Springs subarea.

Recharge of ground water to the Santa Clara Formation is derived from infiltration of stream flow and precipitation. A minor quantity of recharge also may be derived from the adjacent essentially nonwater-bearing rocks.

Ground water apparently moves in a northwesterly direction from the Mission subarea into the alluvium of the Niles subarea east of the Hayward fault. However, even though a ground water gradient exists in this direction, the contribution to the alluvium is minor.

Warm Springs Subarea

The Warm Springs subarea lies to the west of the Mission subarea and includes both the areal expanse of the Warm Springs alluvial apron as well as a portion of the alluvial sediments farther west.

Ground water in the Warm Springs subarea is relatively unimportant because the aquifers are thin and fine-grained and the opportunity for recharge is limited. A considerable number of shallow domestic wells and some irrigation wells are present in the subarea.

The largest known ground water production in the subarea is 90 gallons per minute produced from a well over 200 feet deep. The deepest well with known production figures is 343 feet deep; it produces 75 gallons per minute. The rather low yield of wells in the Warm Springs subarea is explained by the low gravel content of the alluvium. All well logs from the subarea show that the upper 100 feet of alluvium contains less than 17 percent gravel, except near the extreme southeastern boundary where two well logs reported 24 percent gravel. The alluvium is finer-grained near the Mission subarea. Here, well logs usually show only clay in the upper 200 feet of sediments. The gravel percentage and permeability gradually increase toward the west. Throughout the subarea alluvium between

100 and 200 feet below ground surface is more permeable than at either shallower or deeper intervals, and well logs show as much as 37 percent gravel in this interval.

Recharge of ground water in the Warm Springs subarea occurs by infiltration of water flowing across the area in small streams draining the Mission Upland. There is some movement of ground water toward the west into the Niles and San Jose subareas, but because of the low overall permeability very little ground water actually is contributed to these two adjacent subareas.

Santa Clara Ground Water Area

The Santa Clara ground water area occupies the southern portion of the South Bay Ground Water Basin. It is the largest and most highly developed of the three ground water areas. The Santa Clara ground water area is divided into seven separate subareas: San Jose, West Side, Saratoga, Berryessa, Evergreen, Santa Teresa, and Alamitos.

San Jose Subarea

The San Jose subarea includes the San Jose Plain and an adjacent three-mile wide portion of the West Side Alluvial Apron. The San Jose subarea is considered a separate ground water subarea because ground water exists here under nearly completely confined conditions, which makes it unique from any other subarea of the Santa Clara ground water area.

The San Jose subarea is the most important portion of the South Bay Ground Water Basin because water-bearing sediments are extremely permeable, ground water is confined, recharge occurs on three sides, and the total thickness of water-bearing sediments is greater than in any other portion of the basin.

Nature of the Alluvium. The water-bearing sequence in the San Jose subarea consists of a thick sequence of alluvium, overlying sediments of the Santa Clara Formation. The combined thickness of these two units probably exceeds 1,500 feet. However, separation of the two units is not presently possible on the basis of data available. Because most wells in the San Jose subarea do not exceed 1,000 feet in depth, most of the penetrated sediments probably belong to the alluvial sequence. Because of this, the alluvium is considered to be the principal water-bearing unit in the San Jose subarea.

The alluvial sequence in the San Jose subarea is composed of the distal portions of alluvial fans which interfinger with a central outwash plain deposited by ancestral Coyote Creek, Guadalupe River, and Los Gatos Creek. This continental environment has been modified by periodic marine invasions by ancestral San Francisco Bay. The alluvium is coarser and more permeable in the south-central portion; it becomes finer-grained to the north, toward San Francisco Bay. This change of grain size is indicated by the thickness of aquifers. The greatest thickness occurs along the southwestern and southern portions of the subarea, generally to the south of El Camino Real, Santa Clara Street and Alum Rock Avenue.

The decrease in aquifer grain size and thickness toward the Niles subarea is indicated by well logs. This decrease is best illustrated by the upper 400 feet of alluvium. South of San Jose, this upper zone often contains up to 200 feet of permeable materials, but near the boundary with the Niles subarea, it seldom contains more than 50 feet of such materials. In fact, one well south of Guadalupe Slough shows only 23 feet of permeable materials in a total well depth of 900 feet.

The fine-grained nature of the alluvium along the northern boundary of the San Jose subarea is a result of two factors: the periodic presence in the past of a marine environment, and the distance from where the various streams emerged from the hills.

The marine environment which influenced grain size near the present San Francisco Bay contributed to conditions causing ground water to be confined in the San Jose subarea. The presence of continuous aquicludes as far south as San Jose suggests that at various times, ancient bays, lagoons, and sloughs existed as far south as San Jose. In such a marine and paludal environmment, silt and clay would predominate, and the maximum grain size would be sand.

The other factor influencing the fine-grained nature of the alluvium along the northern boundary of the subarea is that streams lose their capacity to carry coarse sediments as their gradient decreases. For example, Los Gatos Creek is currently depositing coarse gravel where it debouches from the Santa Cruz Highland, but it deposits only sand along its channel near San Francisco Bay.

The fact that the above two processes have gone on simultaneously in both the Niles subarea and the San Jose subarea explains the presence of fine-grained alluvium near their common boundary. This fine-grained alluvium nearly isolates ground water in the San Jose subarea from that in the adjacent Niles subarea.

In general, aquifers in the alluvium of the San Jose subarea do not correlate from one well to the next. The deposits between San Jose and Alviso are an exception. Here the 60-foot, 250-foot, 350-foot, and 450-foot aquifers are correlatable and have been named the Agnew sequence. These aquifers are shown in section on

Plate 5. Figure 9 which also shows these aquifers, illustrates the boundary conditions with the southern portion of the Niles subarea.

The Agnew sequence apparently was deposited by Coyote Creek during periods of a continental environment. The presence of the Agnew sequence significantly increases the overall aquifer content in the area between San Jose and Alviso. Therefore, probably only in this small area is there an appreciable interflow of ground water between the Niles subarea and the San Jose subarea.

The decrease in grain size toward the northern boundary of the San Jose subarea suggests that the transmissibility also decreases in the same direction. Specific capacities of water wells in the San Jose subarea imply such a decrease. Lines of equal specific capacity of water wells are shown on Plate 6. This plate shows that along most of the common boundary with the Niles subarea, specific capacities are less than ten. Only in the area east of Alviso do specific capacities exceed ten. This is due to the presence of the Agnew sequence.

The most transmissive portion of the San Jose subarea is indicated by the high specific capacity values in the area between Campbell, Santa Clara and San Jose. This area is roughly circumscribed by the 70-contour on Plate 6.

Well yield in the area surrounding San Jose commonly exceeds 2,000 gallons per minute. The highest yield recorded in the subarea was from a well one mile north of Campbell, which produced 3,110 gallons per minute.

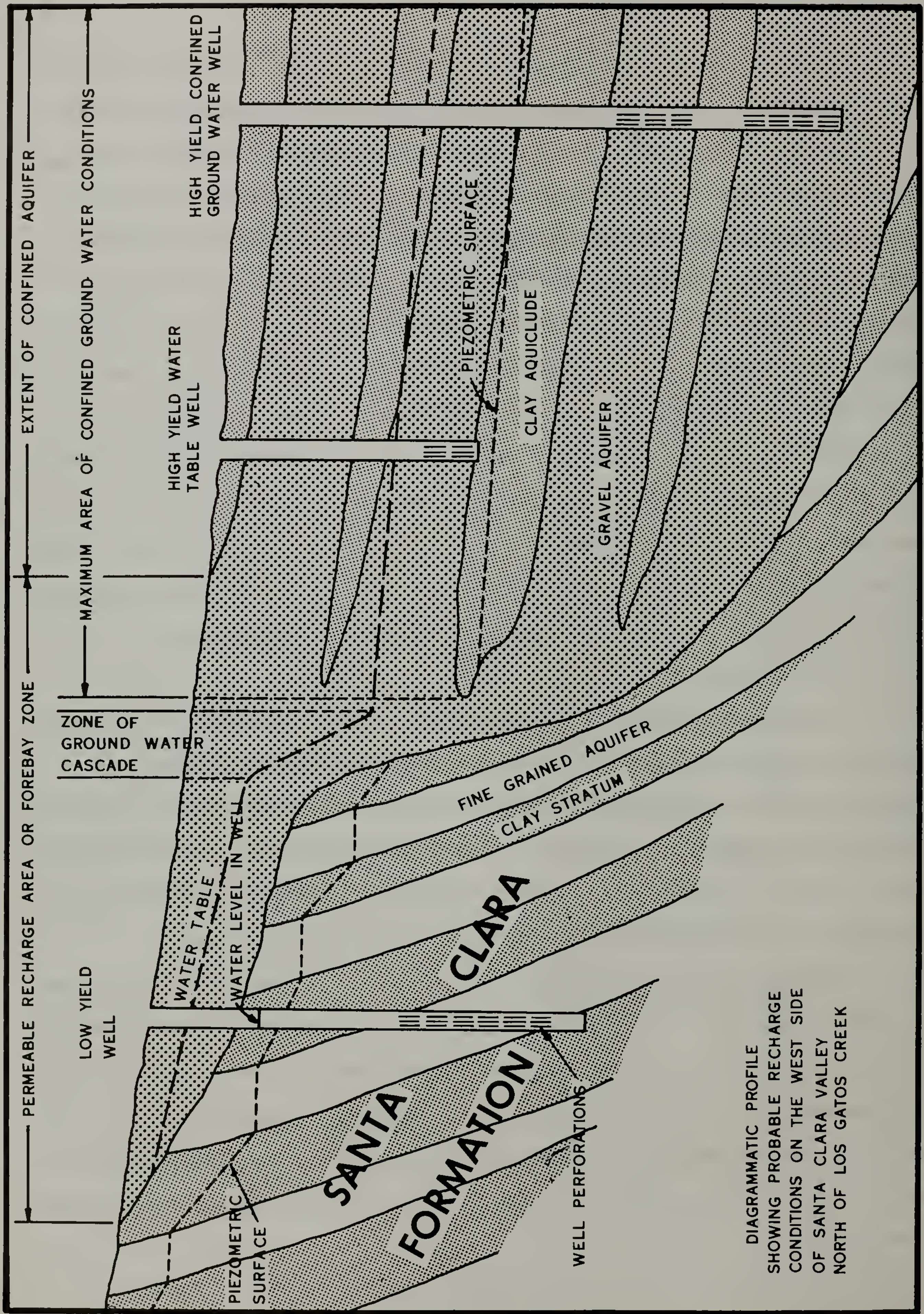
Occurrence of Ground Water. For a number of years it has been known that wells in the San Jose subarea often display different water levels, even in wells only a few feet apart. Attempts to draw water level contour maps often resulted in erroneous configurations of the piezometric surface, depending on which water levels were used.

In the spring of 1963, a detailed canvass of water levels was completed. One of the main objectives was to determine the significance of the various water levels in the South Bay Ground Water Basin. Measurements were made by personnel from cooperating local agencies, supplemented by Department personnel. The measurements showed an erratic pattern of water levels throughout the subarea. When the measurements were subsequently analyzed by using perforation data and well depth, four separate piezometric surfaces were identified. Each surface represented a different depth interval. The depth intervals identified are zero to 150 feet, 150 to 350 feet, 350 to 550 feet, and deeper than 550 feet. Only wells perforated in one of these four zones were used to establish the ground water contours representative of that particular zone. It was found that each successively deeper zone had a deeper piezometric surface, but the configurations of all surfaces were similar.

Interpretation of the piezometric surfaces shows that most subsurface recharge moves from surrounding areas into the shallow aquifers. This is because the transmissibility of the shallow aquifers is apparently higher than that of the deeper aquifers. The different sets of water levels also show that the aquicludes present within the alluvium act as barriers to vertical movement of ground water.

Ground Water Recharge. Ground water in the San Jose subarea is largely confined by thick clay aquicludes. The uppermost aquiclude is sufficiently extensive to prevent appreciable direct recharge from infiltration of rainfall or stream flow. Direct recharge occurs only along Stevens Creek, San Tomas Aquinas Creek, and Los Gatos Creek. Probable recharge conditions for this area are shown diagrammatically in Figure 12.

FIGURE 12

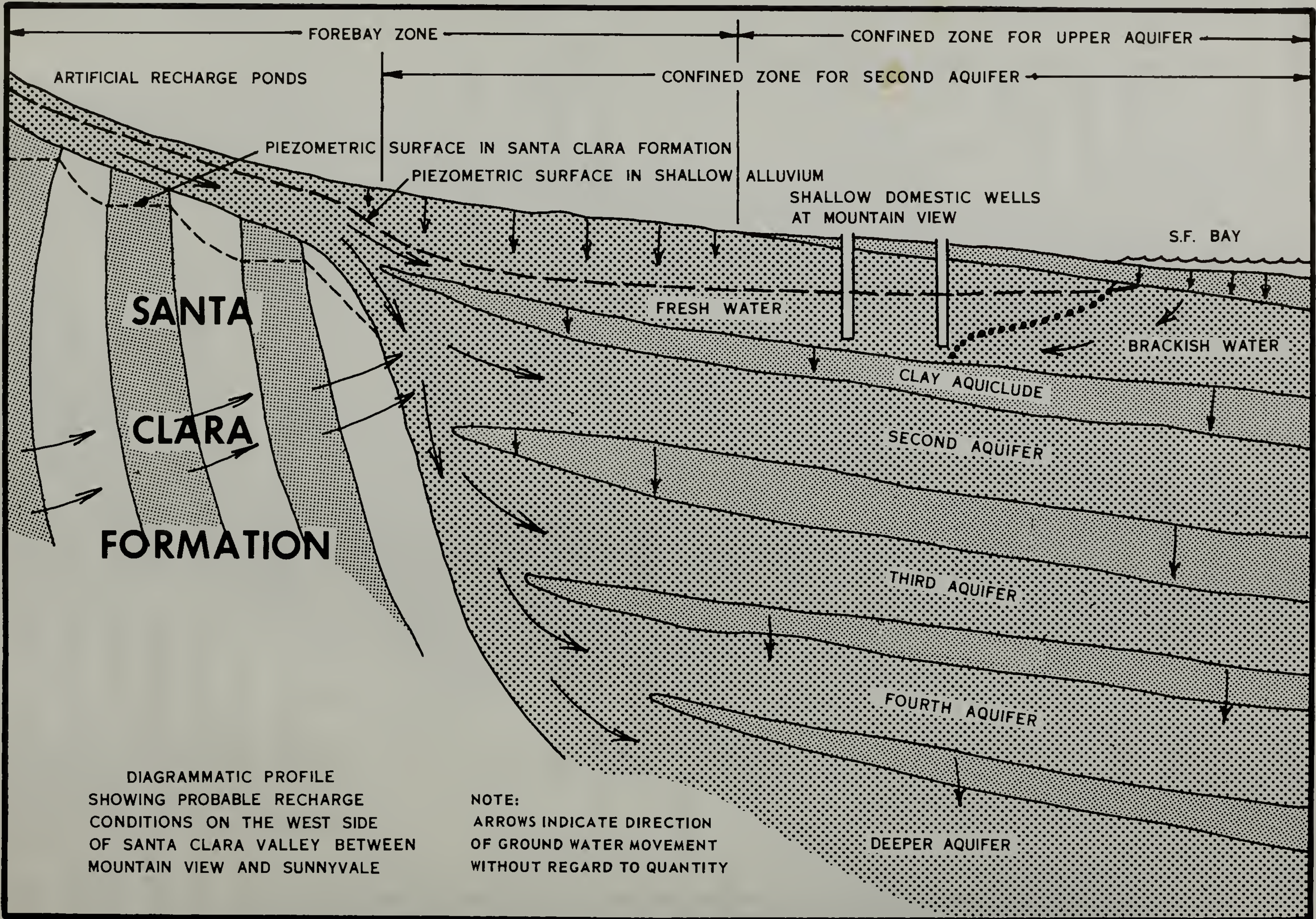


DIAGRAMMATIC PROFILE
SHOWING PROBABLE RECHARGE
CONDITIONS ON THE WEST SIDE
OF SANTA CLARA VALLEY
NORTH OF LOS GATOS CREEK

Most recharge to the subarea occurs indirectly by way of subsurface inflow from the Santa Teresa and West Side subareas. Subsurface inflow occurs principally across the boundary east of Campbell, because it is this latter zone that receives infiltration from Los Gatos Creek, Guadalupe River, and Coyote Creek. Some subsurface inflow is received directly from the Santa Teresa subarea by way of Edenvale Gap. This inflow recharges aquifers in the southeastern portion of the subarea. Most recharge from the Santa Teresa subarea moves around the southern end of Oak Hill, through the West Side subarea near Guadalupe River, and thence into the San Jose subarea.

Other cones and alluvial aprons along the western and eastern sides of the San Jose subarea provide minor quantities of recharge because the alluvium has fairly low transmissive characteristics and the streams crossing these areas are of small extent. The one exception is in the Berryessa subarea along Penitencia Creek. This creek is now providing recharge to aquifers along the eastern edge of the San Jose subarea since artificial recharging of South Bay Aqueduct water began during 1965.

The Mountain View portion of the San Jose subarea probably contains the largest number of shallow water wells in the entire ground water basin. Water level contours indicate that recharge occurs from Stevens Creek. Geologic conditions in the Stevens Creek area south of Mountain View are diagrammatically shown in Figure 13. Water recharged along Stevens Creek east of El Camino Real infiltrates a shallow aquifer underalin by an extensive clay aquiclude. The aquiclude prevents infiltrate from Stevens Creek from moving into the deeper aquifers. Therefore, much of the Stevens Creek water subsequently moves downslope in the uppermost aquifer and toward the bay. Thus, Stevens Creek alone recharges the shallow wells in the



DIAGRAMMATIC PROFILE
SHOWING PROBABLE RECHARGE
CONDITIONS ON THE WEST SIDE
OF SANTA CLARA VALLEY BETWEEN
MOUNTAIN VIEW AND SUNNYVALE

Mountain View area and maintains a high piezometric surface in that portion of the subarea. Because of this high piezometric level, saline water from San Francisco Bay is prevented from moving inland.

Ground Water Discharge. Discharge of ground water from the San Jose subarea occurs only at pumping water wells; there is no subsurface outflow. Production from wells is higher here than anywhere else in the ground water basin, because a large number of deep municipal wells are present which pump nearly continuously. Pumping from these groups of municipal wells has created pumping depressions such as those occurring in Sunnyvale, Santa Clara, and San Jose.

Nearly all of the pumping depressions are reflected on each of the four piezometric surfaces. However, because each group of aquifers is relatively isolated from those adjacent, the similarity of the piezometric surfaces indicates that most of the municipal wells draw their supply from all aquifers penetrated.

Saline Water Intrusion. The use of ground water from wells in the San Jose subarea has depressed the piezometric surfaces to below sea level for some years, causing land subsidence as the materials in the alluvium consolidate. Lowered water levels in the San Jose subarea also invite a southward migration of saline water from San Francisco Bay. Although the situation has persisted for a number of years, only a small part of the subarea near the boundary with the Niles subarea has been affected. Saline water intrusion has not been the problem in the San Jose subarea that it has been in the Niles subarea. This is due principally to the fine-grained nature and great thicknesses of aquicludes along the northern boundary of the subarea. In this northern portion the high percentage of clay in the alluvium and the lack of extensive aquifers to conduct saline water to the south act as effective deterrents to saline water intrusion.

West Side Subarea

The West Side subarea is the most important recharge zone along the west side of the Santa Clara ground water area. It includes that portion of the West Side Alluvial Apron which is underlain by alluvial deposits, and in contrast to the San Jose subarea, contains ground water which is largely unconfined to semi-confined.

Nature of the Alluvium. The total thickness of alluvium underlying the West Side subarea ranges from about 500 to 1,000 feet. Most of the West Side subarea contains only alluvial sediments. However, the western margin is underlain at fairly shallow depth by the Santa Clara Formation. The Santa Clara Formation in this margin area drops off rather abruptly to a considerable depth, which gives rise to a ground water cascade. The location of the cascade is shown on Plate 11. This cascade, named the West Side Cascade in this report, is important to ground water recharge.

The alluvium beneath the West Side subarea is a part of the alluvial fans deposited by streams draining the Santa Cruz Highland. The permeability of these deposits ranges between the high values found in the alluvium of the San Jose subarea to the low values typical of the Santa Clara Formation. The high gravel percentage reported on well logs in the West Side subarea contrasts with the relatively low specific capacities of wells, suggesting that the gravelly portion of the alluvium is rich in silt and clay. This is because much of the alluvial material is made up of reworked sediments of the Santa Clara Formation. The aquifer content of the alluvium decreases with depth. In general, the decrease is gradual without any sharp breaks. Well logs show that the upper 100 to 200 feet of alluvium is very permeable because it is often composed almost entirely of gravel.

The aquifer content of any particular interval in the alluvium increases toward the northeast. Specific capacities of wells also increase in this direction. This combined increase is caused principally by an increasing permeability of the deeper alluvium and an increasing thickness of the more permeable shallower alluvium. Wells in the West Side subarea are usually gravel packed and draw their supply from both upper and lower zones. The more permeable shallow alluvium is generally the principal source of ground water and has a higher specific capacity.

The nature of the alluvial deposits does not change markedly along the boundary between the West Side subarea and the San Jose subarea. The boundary shown on Plate 11 bisects a broad area of change from totally unconfined conditions in the West Side subarea to completely confined conditions in the San Jose subarea. This change in degree of confinement reflects a gradual change in environment in which the alluvium was deposited. The West Side subarea is made up primarily of silt and clay-rich alluvial fans deposited by tributary streams, while the San Jose subarea is composed of coarse-grained sediments deposited by a large trunk stream and interlayered with fine-grained sediments deposited in a shallow water environment.

The thickness of the alluvium between the Saratoga Upland and the West Side Cascade probably does not greatly exceed 200 feet. Here, the alluvium is underlain by sediments of the Santa Clara Formation. South of Los Gatos Creek and northeast of the cascade, the alluvium is considerably thicker because the buried Santa Clara surface drops off to a great depth along what appears to be a very steeply sloping surface. This buried hillfront may be fault controlled as several parallel northwest trending faults are known to cut the Santa Clara Formation in the Saratoga Upland (Plate 3). The sudden termination of the Saratoga Upland at Los Gatos Creek and the alignment of the West Side Cascade parallel to the creek is probably the result of erosion by ancestral Los Gatos Creek. In the underlying deposits, Los Gatos Creek may have eroded a sizeable canyon, which is now filled by permeable materials. The apparent absence of the Santa Clara Formation beneath the West Side subarea south of Los Gatos Creek suggests that Los Gatos Creek and Guadalupe River were both active in eroding the incompetent sediments when this portion of the valley was exposed. The same two streams have probably been instrumental in back-filling this portion of the basin with deposits that are generally more permeable than those beneath the West Side subarea farther north. The alluvial deposits at the mouth of both Los Gatos Creek and Guadalupe River are extremely permeable and are used as spreading grounds for artificial recharge.

Recharge Along the West Side Subarea. Recharge to the West Side subarea occurs primarily during the rainy season by infiltration from streams draining the Santa Cruz Highland. As water in creeks such as Calabazas, Saratoga, and San Tomas Aquinas emerges from the Saratoga Upland, it encounters permeable alluvium and readily infiltrates the channel area. The alluvium conducts the ground water eastward as a perched water zone on top of the buried Santa Clara Formation until it encounters the buried hillfront. Here, it flows over the West Side Cascade and into deeper alluvium. Just east of the cascade, this ground water merges with the main ground water body and subsequently moves toward the San Jose subarea. The ground water differential across the cascade increases gradually from south to north and ranges from 90 feet southwest of Campbell to 140 feet north of Stevens Creek. The zone of this ground water differential is indicated on Plate 11. Most water wells east and west of the ground water cascade are of about the same depth. However, those to the west draw their supply largely from the Santa Clara Formation while those to the east draw their entire supply from alluvium.

In several instances, shallow wells have deeper water levels than nearby deep wells. This suggests that ground water in the Santa Clara Formation has a piezometric surface which is at a higher elevation than the contact between the alluvium and the Santa Clara Formation. Hence, the Santa Clara Formation may actually provide some recharge to the alluvium.

Los Gatos Creek is the most important source of recharge along the western side of the ground water basin. The coarse cobbly alluvium in the creek channel allows high infiltration rates and permits further use as spreading grounds for artificial recharge. Even here, the permeable alluvium is shallow and probably overlies portions of older alluvium that contain fine-grained sediments and therefore are of lower permeability. Consequently, recharged water probably largely moves laterally in a perched manner similar to that described for the area west of the ground water cascade.

The subsurface conditions along Stevens Creek are somewhat different from those of other portions of the West Side subarea, since most recharged water reaches only a shallow aquifer in the alluvium and very little is contributed to the deeper aquifers. These conditions, shown in Figure 12, are the result of a second clay stratum extending farther west than the uppermost clay stratum. Other streams which cross the West Side subarea south of Stevens Creek, overlie a much wider zone of permeable alluvium through which infiltrating ground water recharges the deeper aquifers. The rapid response of deep wells to the effect of recharge along Stevens Creek shows that some infiltrate reaches the lower aquifers, but it probably does so in the zone just east of the ground water cascade.

Saratoga Subarea

The Saratoga subarea lies along the western edge of the ground water basin and is comprised principally of exposures of the Santa Clara Formation. The subarea is relatively unimportant to the production of ground water; however, because of exposures of permeable beds in the Santa Clara Formation, it provides recharge to deeper aquifers.

The Santa Clara Formation in the Saratoga subarea thickens and becomes coarser-grained from west to east. Well logs indicate that the eastern portion of the subarea is underlain by from 500 to 1,000 feet of sediments belonging to the Santa Clara Formation.

The permeability of the Santa Clara Formation is fairly low in spite of the superficially coarse appearance of the formation; however, the permeability gradually increases from west to east. Tolman [33] described the Santa Clara Formation on Stevens Creek as being composed of sands and conglomerates that were silt cemented. A gravel stratum at this site had an estimated permeability of eight gallons per day per square foot. Pump tests from wells near Los Altos indicate that the average permeability ranges from one to ten gallons per day per square foot.

That the permeability increases toward the east is shown by production data from wells located along the eastern edge of the subarea. As shown on Plate 6, three wells produced between 400 and 510 gallons per minute. Logs of wells in the same area show a much higher gravel percentage than do logs of wells located farther to the west. In fact, the percentage of gravel in the upper 400 feet along the eastern edge is locally as high as in many of the wells in the adjacent West Side subarea.

Recharge to the Saratoga subarea occurs both by infiltration of rainfall and infiltration of water flowing in the several streams crossing the subarea. The most notable streams are San Tomas Aquinas Creek, Saratoga Creek, Calabazas Creek, and Stevens Creek. Because the eastward dipping beds of the Santa Clara Formation have been truncated by recent erosion, water in the streams can infiltrate and move downdip toward the valley. Water levels in wells in the subarea stand at elevations from 125 to over 300 feet above sea level, indicating that ground water cannot percolate rapidly in a vertical direction. This is understandable considering the low overall permeability of the formation. However, because the permeability in a lateral direction is much higher than that in a vertical direction, ground water moves downdip and recharges the deeper aquifers in the central part of the basin.

Berryessa Subarea

The Berryessa subarea includes the coelesced alluvial fans of Berryessa and Penitencia Creeks. The deepest well in the subarea is 752 feet, but most wells in the area range from 400 to 600 feet in depth. This depth range probably defines the approximate thickness of the alluvium, since at greater depths, well logs show a rather low gravel content, suggesting the presence of sediments of the Santa Clara Formation. It is likely that the entire alluvial sequence was deposited by Peintencia and Berryessa Creeks.

Most wells in the area are highly productive, usually yielding more than 500 gallons per minute. The maximum known production is 935 gallons per minute. In spite of these high yields, the specific capacity of wells is generally less than ten.

The total aquifer thickness in the Berryessa subarea increases from north to south. Well logs north of Berryessa Creek show a total gravel thickness in the upper 400 feet of alluvium that ranges from nine to 53 feet. The increase in aquifer thickness toward the south is due primarily to the permeable deposits of the Penitencia Creek alluvial fan. The eastern one-third of this fan contains over 25 percent coarse, permeable materials, which gradually diminishes toward the west. In fact, the upper 400 feet of alluvium in the Penitencia Creek fan has a greater total aquifer thickness than nearly any other section of alluvium in the basin. This greater thickness explains the high infiltration capacity along Penitencia Creek which is why this creek was chosen as a major recharge point for imported South Bay Aqueduct water.

Ground water recharge occurs from many streams entering the Berryessa subarea from the Diablo Range, the two most important of which are Berryessa and Penitencia Creeks. In spite of the relative size of Berryessa Creek, examination of the channel suggests that very little recharge actually takes place, because it is underlain by fine-grained deposits. Recharge along Penitencia Creek occurs for a distance of two and one-half miles, nearly to the western limit of the Berryessa subarea.

Water levels in wells in the Berryessa subarea suggest a general westward movement of ground water, but a number of wells have water levels similar in elevation to those in the adjacent San Jose subarea. This indicates either a rapid westward movement of ground water from the Berryessa subarea into the San Jose subarea, a condition of high permeability of the Penitencia Creek fan, or a large amount of ground water is withdrawn from the wells in the Berryessa subarea. Water levels in wells also suggest that more than one piezometric surface is present and that individual aquifers within the subarea are hydrologically separate.

Evergreen Subarea

The Evergreen subarea occupies the extreme southeastern portion of the ground water basin adjacent to the Diablo Highland. It includes the Evergreen Alluvial Apron as well as a one mile wide segment of the San Jose Plain in the northern portion of the subarea.

The Evergreen subarea is a relatively unimportant portion of the ground water basin because the sediments are largely unproductive. It does not contribute significant quantities of ground water to the San Jose subarea to the west.

The thickness of the alluvium of the Evergreen subarea gradually increases from east to west until it probably exceeds 1,000 feet in the northwestern corner of the subarea. Sediments of the Santa Clara Formation undoubtedly underlie the alluvium throughout most of the subarea, and a large outcrop of Santa Clara sediments borders the subarea on the southwest. It is difficult to differentiate between the Santa Clara Formation and the alluvial sediments because here the Santa Clara Formation is considerably more coarse-grained than it is along the western edge of the basin.

Many water wells along the eastern edge of the subarea penetrate bedrock that may be Cretaceous in age. Rocks of this age group probably contribute the highly saline ground water often encountered by wells in the subarea.

Wells in the subarea tend to be fairly deep, usually reaching 400 feet or more; the deepest one is 945 feet in depth. Despite the somewhat unusual depth of the wells, production rarely exceeds 200 gallons per minute and the specific capacity never exceeds ten. One well is an exception to the low production of the area, since it produced 2,425 gallons per minute during its development period and had a specific capacity greater than ten. This well is located at the extreme northern boundary of the subarea just west of Dry Creek. It probably penetrates aquifers that were deposited by Coyote Creek.

In spite of the low yield of water wells, well logs show a rather high gravel content in the sediments penetrated. This combination of low yield and high gravel content is characteristic of areas known to be underlain by the Santa Clara Formation. This is because aquifers are often silt-cemented and therefore are of low permeability. Another indication of low permeability of the sediments in the Evergreen subarea is the water levels in wells. Water levels stand above those in the adjacent San Jose subarea, and have a very steep although irregular, gradient toward the west. The gradient described by these water levels slopes to the northwest at approximately 100 to 500 feet per mile. The shape of the ground water contours suggests that ground water moves both to the north into the Berryessa subarea and to the west into the San Jose subarea. However, because of the fine-grained nature of the sediments and their consequent low permeability, the quantity of ground water actually moving is probably quite low.

Ground water in the Evergreen subarea is essentially unconfined, because no extensive clay layers are known to exist. Recharge occurs from direct infiltration of rainfall as well as from the many streams entering the area from the Diablo Highland. Dry Creek traverses the area along its entire length and is one of the more important recharge streams.

Santa Teresa Subarea

The Santa Teresa subarea occupies the extreme southwestern portion of the ground water basin and encompasses both the Santa Teresa Plain and a one and one-half mile wide portion of the adjacent West Side Alluvial Apron. It includes the recharge area for water infiltrating from Coyote Creek and it supplies ground water to the San Jose subarea by way of underflow. This subarea is second in importance to the West Side subarea as a ground water forebay in the southern portion of the ground water basin.

Nature of the Alluvium. The water-bearing sequence in the Santa Teresa subarea is relatively shallow, with bedrock generally less than 400 feet below ground surface. Because bedrock is at a shallow depth and at a relatively high elevation, the entire water-bearing sequence is probably comprised of alluvium. No sediments of the Santa Clara Formation appear to be present at depth even though there is a small outcrop at the southeastern edge of the area.

The Santa Teresa subarea comprises the upper portion of a nearly flat alluvial fan deposited by Coyote Creek as it meandered over the terrain. Coyote Creek is presently near the eastern edge of the subarea, but in the past it was probably near the western boundary. Coyote Creek at one time may also have flowed between Edenvale Ridge and Oak Hill. Because the sediments in the Santa

Teresa subarea are a part of the Coyote Creek alluvial fan, they are permeable and contain essentially unconfined ground water. The permeability of these sediments is indicated by high production water wells. Production of over 1,000 gallons per minute is not uncommon, as indicated by production figures on Plate 6. In fact, one well, located just south of Edenvale Ridge, produced 2,500 gallons per minute. In addition to high yields, specific capacities are as high as anywhere else in the basin. At least eight wells have specific capacities of over 100 and one has a specific capacity of over 200.

The thickness of the alluvium appears to be quite variable due to ancestral Coyote Creek which cut several gorges in the bedrock in its northward course toward the bay. Well log data indicate that the deepest of these ancient gorges is to the south of Oak Hill, in the area where Guadalupe River and the Almaden Expressway are parallel. A much shallower gorge in the bedrock occurs between Edenvale Ridge and Oak Hill. The logs of two wells in this latter area show that bedrock is between 154 and 242 feet below ground surface. In view of these buried canyons, it is interesing to note that bedrock is exposed along the present course of Coyote Creek as it passes through Coyote Gorge, east of Edenvale Ridge.

Occurrence and Movement of Ground Water. The Santa Teresa subarea is recharged primarily by infiltration from Coyote Creek. At Coyote Narrows, both underflow and effluent seepage occur. Underflow is indicated by a steepening in the ground water gradient north of the narrows to form a ground water cascade. Water levels drop 40 feet across this cascade in a distance of approximately one mile, as shown on Plate 11. This is in sharp contrast to the flat gradients in the Santa Teresa subarea to the north. The cascade indicates that ground water moving northward attains a level nearly coincident with that of the ground surface before passing through the narrows. It then moves northward and downward to the gently sloping water table in the Santa Teresa subarea.

Nearly all recharge that occurs from Coyote Creek takes place in the Santa Teresa subarea. Exposures of bedrock in Coyote Gorge precludes infiltration at that point. Furthermore, examination of the Coyote Creek channel, north of the gorge shows that little infiltration takes place there. Therefore, recharge in the southern portion of the adjacent San Jose subarea occurs primarily by subsurface underflow from the Santa Teresa subarea.

Water levels in wells in the Santa Teresa subarea have a very flat gradient toward the northwest, showing that ground water moves into both the San Jose and West Side subareas. The flat gradient also shows that the alluvium is permeable and that ground water cannot easily escape to the north. To reach the San Jose subarea, ground water must move from the Santa Teresa subarea through the Edenvale Gap. The alluvial-filled channel in Edenvale Gap is probably no deeper than 250 feet. Consequently, even though the channel contains very permeable material, its cross-sectional area is small in comparison to the total volume of material in the Santa Teresa subarea. Thus, Edenvale Gap forms a constriction in the subsurface travel path of the northward percolating ground water. This constriction causes a 90-foot ground water cascade to the northeast of the gap. Well logs show that the alluvium northeast of the gap is considerably thicker than in the gap itself, thereby allowing ground water to move to greater depths in that direction.

Ground water moves into the West Side subarea between Oak Hill and the northwestern end of the Santa Teresa Hills. Here, deposits from both Coyote Creek and Los Gatos Creek interfinger. Both specific capacity and well production are considerably lower in this interfingering zone than they are in the central portion of the Santa Teresa subarea. This suggests that the permeability of the West Side deposits is considerably less than that of the Santa Teresa deposits. Ground water contours do not become steeper as expected, but instead slope toward the northeast. The fact that ground water contours do not change shape near Oak Hill shows that the surrounding alluvium is permeable right up to the bedrock contact. These conditions are logical in view of the geologic history of the area, which indicates that Oak Hill has been partially buried by permeable deposits laid down by Coyote Creek and Los Gatos Creek.

Considering the high yield of water wells in the Santa Teresa subarea and the relatively shallow nature of the alluvium, well logs only occasionally show a total aquifer thickness exceeding 50 feet per 100 feet depth. This suggests that the gravel layers must be highly permeable. In general, the aquifer content decreases with increasing depth. In Section 10, T. 8 S., R. 1 E., two deep wells north of Downer Avenue report a zero gravel content below 200 feet. These wells appear to be an exception to the norm, however, as most well logs show more than 25 percent gravel per 100 foot increment throughout the full depth penetrated. In general, the gravel content of the upper 100 feet of alluvium averages about 40 percent and ranges up to a maximum of 70 percent.

Alamitos Subarea

The Alamitos subarea occupies the extreme southern portion of the ground water basin; it is adjacent to the Santa Cruz Highland. The subarea is a relatively unimportant portion of the ground water basin because the water-bearing sediments are thin and relatively fine-grained. The alluvium ranges in thickness from approximately 30 to 60 feet toward the southeast to about 130 feet in the northwest. Nonwater-bearing bedrock underlies the alluvium.

The total thickness of water-bearing materials within the alluvium ranges from 5 to 45 feet. While these values appear to be high, considering the thickness of alluvium, well production is low. Of five wells with known production data, the highest produced only 40 gallons per minute and the deepest wells in this group produced only 30 gallons per minute. The low production characteristics of the sediments are further substantiated by specific capacities that are all less than ten.

Contours show that ground water moves toward the northwest into the West Side subarea. However, because of the low permeability of the alluvium, the quantity of underflow contributed to the West Side subarea is probably minor.

San Mateo Ground Water Area

The San Mateo ground water area extends along the western side of San Francisco Bay north of Adobe Creek. The area is divided into the San Francisquito and Belmont subareas.

San Francisquito Subarea

The San Francisquito subarea is on the western side of San Francisco Bay opposite Dumbarton Strait. The extent of the subarea is shown on Plate 11. The San Francisquito subarea is the most important ground water producing area on the western side of the San Francisco Bay and for many years it supplied the municipal needs of Stanford University and the City of Palo Alto. Today, only the university still pumps large quantities of ground water from this subarea.

Water-Bearing Sequence. The bedrock surface beneath the San Francisquito subarea forms a southeastward dipping trough (see Plate 10). The thickness of the water-bearing sequence above this bedrock surface ranges from about 400 feet at the northern end to over 1,000 feet at the southern end. Within this water-bearing sequence, individual sand and gravel zones are discontinuous and cannot be correlated from one well to the next. The Santa Clara Formation is exposed along the southwestern boundary of the subarea and undoubtedly underlies the alluvium along the western boundary probably at shallow depth. According to well log data, the shallow portions of the subarea have gravel beds that are intermixed with silt and clay and appear similar to materials reported on logs of wells penetrating the Santa Clara Formation. Because of this, separation of the Santa Clara Formation from the alluvium is not possible on the basis of physical description alone.

A rough separation between the Santa Clara Formation and the alluvium may be determined from specific capacity data of wells tapping the two units. The contours presented on Plate 6 show that within the San Francisquito subarea, there is an elongated area within which all wells have specific capacities greater than ten. This elongated area is parallel to the bedrock trough. In addition, areas known to be underlain by sediments of the Santa Clara Formation have wells in which the specific capacity is always less than ten. Therefore, the closed 10-contour probably encompasses an area of thick alluvium. Wells within this area apparently draw their water from the alluvium and not from the underlying Santa Clara Formation. Specific capacities as high as 40, shown at two locations in the San Francisquito subarea would be unlikely if the sediments encountered belonged to the Santa Clara Formation. Each of the two closed 40-contours shown on Plate 6 is based on a single well. The southernmost well is one of the deepest in the subarea. It is 1,068 feet deep and produces the greatest yield in the subarea: 1,840 gallons per minute. Production of this magnitude has never been approached before by any well penetrating the Santa Clara Formation.

Ground Water Movement. The upper 100 feet of alluvium in the San Francisquito subarea has a consistently large total thickness of aquifers; it occasionally exceeds 50 feet per 100 feet of depth. Water level data suggest that ground water in shallow aquifers moves eastward to recharge the Newark aquifer in the adjacent Niles subarea.

Ground water in the San Francisquito subarea is recharged from four principal sources: infiltration along San Francisquito Creek, infiltration from Lake Lagunita, deep percolation and subsurface inflow. Sokol 29/ states that the total annual replenishment to the subarea amounts to about 3,000 acre-feet. Of this amount, 700 acre-feet per year is contributed by Lake Lagunita, located in Section 10, T. 6 S., R. 3 W.

The most permeable portion of the San Francisquito subarea is along the hillfront from Lake Lagunita northwesterly for a distance of about one mile. This portion extends eastward from the hillfront along San Francisquito Creek a distance of one-half mile. The fine-grained nature of the alluvium in the creek channel farther downstream suggests that little additional infiltration occurs there.

Discharge of ground water from San Francisquito subarea occurs largely from pumping wells. Prior to 1962, there was an annual pumpage of 7,500 acre-feet, which caused water levels in the subarea to decline five feet per year. In past years, the City of Palo Alto pumped the largest quantity of ground water and Stanford University pumped the second largest quantity. In 1962, the City of Palo Alto began purchasing water from the City of San Francisco and subsequently discontinued the pumping of ground water. Stanford University continues the use of ground water.

Many different ground water levels have been recorded in wells in the San Francisquito subarea. The different levels are caused by the difference of piezometric heads in individual aquifers having little direct hydraulic continuity. In spite of this, deep wells in the southern portion of the subarea appear to reflect active pumping by the Stanford University wells. No water-level gradient is evident on the west side of the wells, showing that the nonwater-bearing rocks exposed there create an effective barrier to subsurface inflow from that direction.

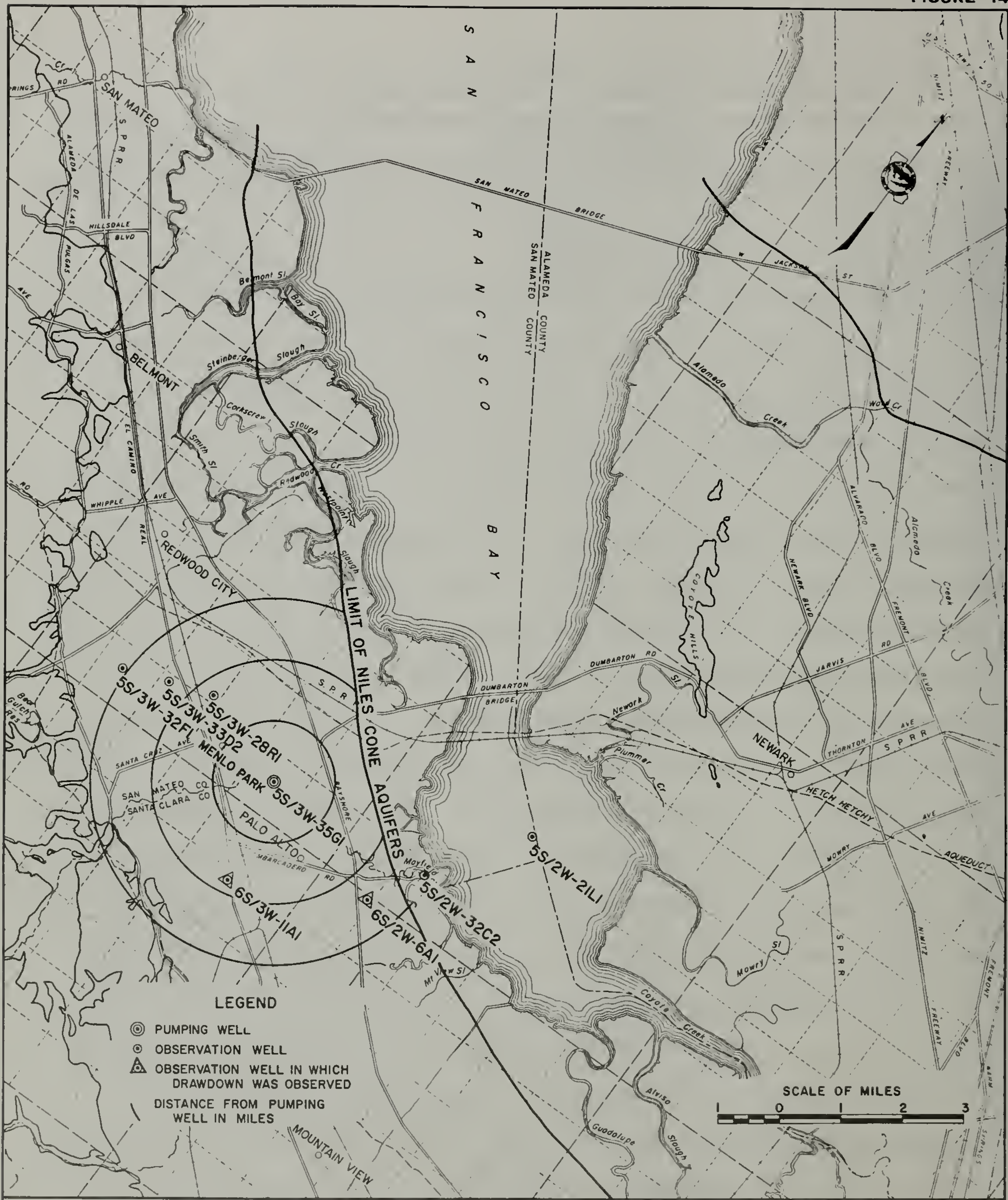
Aquifer Coefficients. The results of four pump tests to determine aquifer coefficients in the San Francisquito subarea were presented by Sokol [29/] and are shown in Table 7.

Table 7
AQUIFER COEFFICIENTS IN SAN FRANCISQUITO SUBAREA

Well Number	Transmissibility (gal/day per sq. ft.)	Storage Coefficient
6S/3W-10K2	270	---
6S/3W-10L1	20,000	0.05
6S/3W-11B1	118,000	0.00126
6S/3W-12D1	48,800	0.000186

The tests were performed in the area west of El Camino Real and south of San Francisquito Creek. The values represent conditions progressively farther west toward the apex of the alluvial fan and show that in general the transmissibility of the alluvium increases in that direction. Conversely, the storage coefficient decreases, suggesting that confining conditions become less. Sokol [29/] states that Bradbury and Associates while investigating the area near Lake Lagunita, determined that the upper zone in the cone is unconfined and has an average transmissibility of 50,000 gallons per day per square foot, while a confined lower zone has an average transmissibility of 250 gallons per day per square foot. Both aquifers are recharged at Lake Lagunita. No thickness is given for the upper zone, but it appears reasonable to assume that a transmissibility of 50,000 would represent the alluvium, and one of 250 the Santa Clara Formation.

Continuity of Aquifers. To determine the continuity of aquifers in the San Francisquito subarea, well 5S/2W-35G1 owned by the City of Palo Alto, was pumped for nine days while drawdown effects were monitored in seven observation wells in the surrounding area, as shown in Figure 14. From May 22 to June 4, 1963, the well was pumped continuously at a rate of more than 1,000 gallons per minute. The distances to the observation wells and the drawdown observed in each is shown in Table 8.



LOCATION OF WELLS USED TO DETERMINE THE CONTINUITY OF AQUIFERS IN THE SAN FRANCISQUITO CONE

Table 8
AQUIFER CONTINUITY PUMP TEST
SAN FRANCISQUITO SUBAREA

Well Number	Distance to Pumping Well 5S/2W-35G1	Magnitude of Drawdown
5S/2W-21L1	22,000 feet	0
5S/2W-32C2	14,500 feet	0
5S/3W-28R1	9,700 feet	0
5S/3W-32F1	16,500 feet	0
5S/3W-33D2	13,000 feet	0
6S/2W- 6A1	11,400 feet	0.98 feet
6S/3W-11A1	9,500 feet	0.40 feet

In spite of the high pumping rate of the Hale Street well, only wells 6S/2W-6A1 and 6S/3W-11A1 showed any response. Drawdown in well 6S/3W-11A1 began 20 hours after pumping started, and recovery began 14 hours after the pump was stopped. In well 6S/2W-6A1, drawdown started after 26 hours and recovery began after 96 hours. This test showed that ground water conditions in the San Francisquito subarea are considerably less confined that those beneath San Francisco Bay.

The location of the boundary between the Niles subarea and the San Francisquito subarea can be inferred from two facts observed during the test. Of the seven observation wells, 5S/2W-21L1 and 5S/2W-32C2 show the effects of tidal loading, known to be characteristic of Niles subarea aquifers. Also, drawdown was not noted in well 5S/2W-32C2 even though it is only 3,100 feet farther away from the pumping well than is well 6S/2W-6A1, which showed nearly a foot of drawdown. These data suggest that the Niles subarea aquifers end at some point between well 5S/2W-32C2 and well 6S/2W-6A1.

The results of aquifer continuity tests performed in both the Niles and the San Francisquito subareas indicate that below a depth of 180 feet there is little movement of ground water between the two subareas. The tests further suggest that the subareas are separated from each other; probably the result of the high clay content of the distal ends of the respective alluvial fans.

Belmont Subarea

The Belmont subarea lies in the northwestern part of the San Mateo ground water area. It includes the small alluvial fans located at the base of the Santa Cruz Mountains, grouped as the San Mateo Alluvial Apron on Plate 2, as well as much of the Bay Plain on the western side of San Francisco Bay.

Because the alluvium is relatively thin, fine-grained and generally unproductive, the Belmont subarea is a relatively unimportant portion of the ground water basin. The wells which encountered bedrock show that the water-bearing sequence is less than 500 feet thick throughout the subarea and usually not more than 300 feet thick.

San Mateo Creek has the largest watershed of any stream in the subarea and has therefore deposited the largest alluvial fan. The San Mateo alluvial fan is also the most permeable portion of the subarea. The aquifer thickness of the upper 100 feet of the subarea often exceeds 50 feet per 100 feet of thickness, but markedly decreases toward the bay. The logs of most of the wells near the eastern limit of the subarea report no aquifers at all.

A similar pattern of decreasing aquifer thickness toward the bay is evident from well logs throughout the Belmont subarea. Apparently the streams draining the west side of the bay have been unable to carry coarse material very far into the marine environment that persisted near the bay. Hence, the eastern portion of the subarea is nearly devoid of aquifers.

Most of the water wells in the Belmont subarea are less than 300 feet deep, produce only small quantities of water, and have low specific capacities. The general lack of wells in the subarea suggests that the alluvium is not very permeable; no well is known to have a specific capacity greater than ten. In addition no wells are known to produce more than about 350 gallons per minute.

Along the western edge of the Belmont subarea, ground water is recharged by infiltration along the many small streams draining the adjacent uplands. Ground water probably moves eastward toward San Francisco Bay. The relationship between aquifers in the Belmont subarea and those in the Niles subarea is not completely understood. The lack of aquifers in the upper 100 feet of alluvium along the eastern edge of the subarea suggests that the Newark aquifer of the Niles subarea does not merge with any aquifers in the Belmont subarea. However, some aquifers in this subarea may be in close proximity to the deeper aquifers of the Niles subarea. If this is the case, some ground water may move eastward. However, the low total thickness of aquifers along the boundary between the two subareas greatly limits the quantities of ground water movement.

The total thickness of aquifers in the alluvium in the Belmont subarea appears to increase toward the boundary with the San Francisquito subarea; however, even there, no aquifers are present in the upper 100 feet of alluvium.

ATTACHMENT 1
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ATTACHMENT 2
PHYSIOGRAPHIC FEATURES

The physiographic features of the South Bay Drainage Unit shown on Plate 2 and described in this attachment are:

1. The bordering highlands, consisting of portions of the Santa Cruz Mountains and the Diablo Range.

2. The bordering foothills lying near the base of the mountains, consisting of the Mission, Saratoga, and San Mateo Uplands.

3. The alluvial apron along the base of the mountains and foothills, which includes the Alamitos, West Side, San Mateo, Evergreen, Berryessa, Warm Springs, and Mission Alluvial Aprons, and the San Francisquito, Niles, Dry Creek, and San Leandro Cones.

4. The interior plains, consisting of the Santa Teresa, San Jose, and Bay Plains.

5. The hills rising above the plains, including Edenvale Ridge, Oak Hill, Coyote Point, and Coyote Hills.

6. San Francisco Bay.

Bordering Highlands

The mountainous areas comprising the bordering highlands provide conditions favorable to high rainfall and have elevations necessary for active erosion. They also enclose the bay depression, in which the products of erosion accumulate. The formations comprising these mountainous areas are essentially nonwater-bearing, but during dry periods they support stream flow from many springs and seeps.

Santa Cruz Highland

That portion of the Santa Cruz Mountains within the study area is named the Santa Cruz Highland. The crest of the highland parallels Skyline Boulevard and ranges in elevation from 3,798 feet at Loma Prieta on the south, to 2,060 feet at King Mountain on the north. The highland, which is made up of nonwatering-bearing rocks, decreases in width and ruggedness toward the north and gradually merges with the rolling foothills of the San Mateo Upland.

The Santa Cruz Highland receives an average annual rainfall of about 40 inches. The relatively high rainfall and eastern exposure accounts for its dense forest cover.

Diablo Highland

The Diablo Highland rises abruptly from the valley floor to elevations of 2,187 feet along Sunol Ridge and 3,294 feet along the divide south of Calaveras Reservoir. The crest of the Diablo Highland coincides with the boundary between the South Bay Drainage Unit and the Livermore and Sunol Drainage Units, as shown on Plate 1. Concordant summits along this crest are remnants of an old, uplifted, dissected erosion surface. The rocks exposed in the Diablo Highland are nonwater-bearing. However, along the western edge of the highland, small remnants of the Santa Clara Formation and other moderately permeable rocks of Tertiary age provide modest quantities of ground water for domestic purposes.

The Diablo Highland receives about 22 inches of precipitation annually. In contrast to the Santa Cruz Highland, the Diablo Highland is largely grass covered, with trees common only in the canyons.

Bordering Foothills

In only three areas are bordering foothills distinctly developed. These areas are the San Mateo and Saratoga Uplands, on the west side of the valley, and the Mission Upland on the east side of the valley.

The Mission and Saratoga Uplands are underlain by sediments of the Santa Clara Formation, while the San Mateo Upland is underlain mostly by older formations of late Tertiary age. All of these formations are relatively soft and are more subject to erosion than the more competent rocks comprising the adjacent highlands. The subdued, gentle topography that characterizes an upland is due both to the incompetence of the exposed formations and to a partially preserved erosion surface developed during the Pleistocene epoch.

Mission Upland

The Mission Upland is an eight square mile, triangular area located at the base of the Diablo Highland and between the Mission and Hayward faults. It includes the largest exposure of the Santa Clara Formation on the eastern side of the valley. The rolling upland surface slopes westward from an elevation of approximately 600 feet to about 200 feet at its western margin.

San Mateo Upland

The San Mateo Upland extends along the foot of the Santa Cruz Mountains from beyond the northern limit of the investigation, southward to the vicinity of Los Altos. The western boundary of the upland lies along an elongated valley paralleling the San Andreas fault zone and is occupied in part by Crystal Springs Reservoir.

The upland is characterized by a low rolling topography developed on sediments ranging from the Franciscan Formation to the Santa Clara Formation. The upland locally is steep but generally ranges in elevation from about 100 feet along the eastern edge to heights not exceeding 800 feet. The gentle nature of the upland has created an area of attractive building sites and is now well populated.

The natural drainage along the San Andreas rift zone has historically been eastward along San Mateo Creek. Crystal Springs Dam and Reservoir are situated on the upper reaches of San Mateo Creek.

Saratoga Upland

The Saratoga Upland includes the largest exposure of the Santa Clara Formation on the western side of the valley. The upland is about two miles wide between the West Side Alluvial Apron and the Santa Cruz Mountains. It extends along the mountain front for a distance of 16 miles, between Los Gatos on the south, and Los Trancos Creek on the north. The upland ranges in elevation from about 800 feet at the base of the Santa Cruz Highland, to an elevation of approximately 320 feet at its boundary with the West Side Alluvial Apron. The surface of the Saratoga Upland is crossed by many small streams and is therefore considerably dissected. The southern two-thirds of the upland is underlain by sediments of the Santa Clara Formation. The northern one-third is underlain by small areas of easily erodible Santa Clara Formation overlying older Tertiary materials.

Alluvial Aprons and Cones

Except for the bordering foothills, the highest portion of the ground water basin is composed of a series of alluvial aprons and cones that slope toward the interior plain. These features have been divided into several units separated by physiographic boundaries. Where a number of separate alluvial fans have coelesced into a single unit, the term alluvial apron is used. The alluvial aprons in the study area, in order of decreasing size, are: the West Side, Berryessa, Evergreen, Alamitos, San Mateo, Warm Springs, and Mission. In contrast to these alluvial aprons, certain streams have formed distinct, separate alluvial cones. The cones, in order of decreasing size, are: the Niles, San Francisquito, San Leandro, and Dry Creek. All of these aprons and cones are shown on Plate 2.

West Side Alluvial Apron

The West Side Alluvial Apron lies along the west side of the valley between the Saratoga Upland and the San Jose Plain. It is only one mile wide at its northern boundary with the San Francisquito Cone and is bounded on the south by the Santa Teresa Plain. The area slopes eastward at about 75 feet per mile in the narrow northern section and about 50 feet per mile in the wider southern portion. The elevation along the western border is about 320 feet and the eastern border merges imperceptibly with the San Jose Plain at an elevation of about 120 feet.

Berryessa Alluvial Apron

The Berryessa Alluvial Apron is bounded on the south by the Alum Rock area of San Jose and on the north by Milpitas. It extends westward from the hillfront and has a maximum width of three miles along Penitencia Creek. It has a surface gradient of approximately 80 feet per mile. This unit is made up of the merging alluvial cones of Berryessa Creek on the north, and Penitencia Creek on the south. Penitencia Creek is the most active depositor of alluvium on this side of the valley.

Evergreen Alluvial Apron

The Evergreen Alluvial Apron lies at the base of the Diablo Highland at the southeastern edge of the basin. It has a maximum width of about three miles and has an alluvial gradient of up to 200 feet per mile. Dry Creek has been the most important depositor of alluvium, but Babb Creek and Flint Creek also contribute.

Alamitos Alluvial Apron

The Alamitos Alluvial Apron is a narrow northwest trending arm of alluvium adjoining the south side of the West Side Alluvial Apron. It is separated from the Santa Teresa Plain by the intervening Santa Teresa Hills. The area slopes gently to the north at a gradient of 30 to 40 feet per mile. It is comprised of outwash from Arroyo Calero and Alamitos Creek. The northwestern boundary of the apron is along the edge of the alluvial fan of Guadalupe River.

San Mateo Alluvial Apron

The ground water basin west of San Francisco Bay and north of the San Francisquito Cone is characterized by a lack of large alluvial fans. The small streams that drain the low-lying San Mateo Upland, the largest of which is San Mateo Creek, have not developed large fans. Consequently, the San Mateo Alluvial Apron has a maximum width of only two miles near San Mateo and only about one mile at its southern end. The gradient of the San Mateo Alluvial Apron is eastward at about 75 feet per mile.

Warm Springs Alluvial Apron

The Warm Springs Alluvial Apron is one of the smallest alluvial aprons found along the base of the Diablo Highland. It separates the Mission Upland from the Interior Plain, is less than one mile in width, and has been deposited by Agua Caliente, Toroges, Agua Fria, Scott, and Calera Creeks. The apron slopes westward at approximately 160 feet per mile and is marked on the south by a topographic depression which is only 20 feet above sea level. The fact that streams have not been able to form a wider alluvial apron is important to the present position of San Francisco Bay. It is this lack of stream activity that has allowed the Bay Plain to persist near the hillfront in the Warm Springs area.

Mission Alluvial Apron

The Mission Alluvial Apron has an area of approximately two square miles and is located east of the Hayward fault, at the base of the Diablo Highland. It slopes northwestward toward the apex of the Niles Cone at a gradient of approximately 240 feet per mile and has been formed by outwash from Mission Creek.

Niles Cone

The Niles Cone extends westward about 6½ miles from the base of the Diablo Highland to the Coyote Hills and the edge of the Bay Plain. The apex of the Niles Cone is at an elevation of less than 100 feet. It slopes westward at only 10 feet per mile and merges imperceptibly with the Bay Plain. The boundary between the Niles Cone and the San Leandro Cone on the north along West Alquire Road is marked by a topographic low with an elevation of only 20 feet above sea level. A similar topographic low exists at the southern margin of the Niles Cone in the vicinity of Irvington, where the land surface near the Hayward fault is only 40 feet above sea level. The deposition of the alluvium of the Niles Cone and the San Francisquito Cone on the opposite side of the valley have apparently contributed largely to the formation of Dumbarton Strait.

San Francisquito Cone

The San Francisquito Cone, located on the San Mateo-Santa Clara County line, is the largest alluvial cone on the northwestern side of the basin. It extends east from the edge of the hills for a distance of about five miles at a gradient of approximately 30 feet per mile.

San Leandro Cone

The San Leandro Cone extends westward from the hillfront for a distance of about four miles. It has a gentle gradient of only 30 feet per mile and is separated from its neighboring cones to the north and south by topographically low areas. The topographic low north of the cone one-half mile from the edge of the hills attains an elevation of only 30 feet above sea level.

Dry Creek Cone

The Dry Creek Cone is a small alluvial fan superimposed on the northern portion of the much larger and more gently sloping Niles Cone. The fan has been deposited by Dry Creek and has a gradient of approximately 50 feet per mile. This superimposed position suggests that the Dry Creek Cone is a recent feature, perhaps resulting from the recent capture of a larger watershed by Dry Creek.

Interior Plain

The central and southern portions of the ground water basin are characterized as an area of low relief, slight gradient, and low elevation. The northern portion of the Interior Plain lies at an elevation of less than 20 feet, but gradually rises from the bay southward to a maximum elevation of 240 feet at Coyote Narrows. The boundary between the Interior Plain and the surrounding alluvial cones and aprons is an arbitrary division marked by a nearly imperceptible change in slope.

The Interior Plain is divided into three areas: the Bay Plain, the San Jose Plain, and the Santa Teresa Plain.

Bay Plain

The Bay Plain is that area surrounding San Francisco Bay which has an elevation between lower low tide and higher high tide. The area, shown as marshland on Plate 3, varies in width from about one-half mile to more than three miles. It is characterized by marshland and sloughs, and includes the original marshes that either have been filled or converted to salt evaporation ponds. Much of the marshland between the larger sloughs is inundated only during the highest of tides as it is protected from normal tidal erosion by marsh vegetation. Undeveloped portions of the Bay Plain are covered by an intricate network of meandering sloughs, each in hydraulic continuity with its neighbor. The main distinction between the Bay Plain and the neighboring San Jose Plain is the type of land use, the vegetative cover and the type of soil development.

San Jose Plain

The San Jose Plain occupies the central portion of Santa Clara Valley between the Bay Plain, on the north, the Santa Teresa Plain on the south, and the steeper alluvial aprons to the east and west. The plain slopes northward at a gradient of less than 15 feet per mile and represents an outwash plain for streams which emerge from the surrounding highlands. The San Jose Plain is underlain by the most productive portion of the ground water basin, and in turn has suffered the most severe land subsidence as a result of ground water withdrawal.

Santa Teresa Plain

The Santa Teresa Plain occupies the southern portion of the ground water basin north of Coyote Narrows. The plain slopes northward at about 15 feet per mile, from an elevation of 240 feet at Coyote Narrows to about 160 feet at Oak Hill. The northern boundary is marked by Oak Hill and Edenvale Ridge. Here, the plain merges imperceptibly with the adjacent San Jose Plain by way of the one-mile wide Edenvale Gap. The western boundary of the plain is marked by an elongated depression along Canoas Creek, which occurs at the 160-foot topographic contour. The Santa Teresa Plain is the outwash plain of Coyote Creek. Along its western boundary is a zone of deposition from Guadalupe River.

Hills Rising Above the Interior Plain

The formation of alluvial fans extending from the mountain front has gradually buried most of the ancient rugged topography which developed on Miocene and older rocks. However, there are still a few isolated hills of older rocks rising out of the Interior Plain, as yet unburied by deposition. The locations of these hills are shown on Plate 3.

These features are important to the ground water study because along with their broader, buried bases, they act as barriers to the movement of ground water. The most important outcrops are Coyote Point, Coyote Hills, Oak Hill, and Edenvale Ridge. These features are shown on Plate 2.

Coyote Point

Coyote Point, also called Point San Mateo, is the most northerly of the nonwater-bearing outcrops. It is northeast of San Mateo and forms a projection of land extending into San Francisco Bay. It rises sharply out of the Bay Plain to an elevation of more than 75 feet above sea level and is a prominent local landmark.

Coyote Hills

Coyote Hills consists of six separate outcrops of rocks of the Franciscan Formation which rise above the Bay Plain near the eastern edge of San Francisco Bay. The hills extend northwesterly for about five miles. They are about one-half mile wide and rise to a maximum elevation of more than 290 feet. The northernmost exposure is name Turk Island, while the southernmost exposure is a barely perceptible rise in the ground surface just south of the Hetch Hetchy Aqueduct. These hills are an important barrier to ground water in the Niles Cone.

Oak Hill

Oak Hill is a prominent outcrop of nonwater-bearing rock located just south of San Jose. It is about $1\frac{1}{2}$ miles across and rises 280 feet.

Edenvale Ridge

Edenvale Ridge trends in an east-west direction for about 1-3/4 miles. It rises to a maximum elevation of 350 feet and is located one mile southeast of Oak Hill. Both Edenvale Ridge and Oak Hill are effective barriers to both ground water and surface water. Recharge from Coyote Creek moves between the two hills through Edenvale Gap. Surface water moves through Edenvale Narrows, a narrow strip of alluvium between Edenvale Ridge and the main mountain mass to the east.

San Francisco Bay

San Francisco Bay covers most of the north central portion of the area of investigation. The bay in this area is quite shallow, averaging less than six feet in depth. A natural channel extends from Coyote Creek through the center of the bay to Dumbarton Strait and continues northward near the western shore to beyond San Mateo Bridge. The channel is about 30 feet in depth north of Dumbarton Strait and about 12 feet in depth farther south. The channel in the southern portion of the bay must be dredged so that large ships can reach Redwood City and smaller craft can reach Alviso.

South of San Mateo Bridge the salinity of the bay is frequently higher than would normally be expected. A chloride content as high as 21,000 parts per million was measured south of Dumbarton Strait, in contrast to a normal chloride content of 18,000 parts per million in sea water. The increase of salinity of the South Bay is probably due to the high evaporation rate in this shallow body of water. Evaporation measurements by Leslie Salt Company at their salt ponds show that wind, invariably present in the South Bay, contributes to the high evaporation rate. Historically, winter periods of heavy stream runoff probably freshened the bay water. The large number of conservation projects on streams entering the South Bay have reduced the inflow and the freshening.

The length of this portion of the bay in relation to its width contributes to greater extremes in amplitude of tidal fluctuations than is found in other parts of the bay. This amplification reaches its maximum at Guadalupe River and Mud Slough, where the mean tidal range is 7.4 feet and the diurnal tidal range is 9.1 feet. Extensive flooding of the low marshlands south of the Bay, normally occurring during higher high tide, becomes a threat to low-lying communities near the Bay Plain during the infrequent periods of southerly gales and high stream runoff. The City of Alviso and surrounding farmland has been flooded many times in the past when bay water or storm runoff has overtopped flood control levees. This has become an increasing problem in recent years because of ground subsidence at the southern end of San Francisco Bay.

Subsidence and extreme high tides have created problems for the Southern Pacific Railroad, north from Alviso to Newark, because high tides actually cover the rails along much of this route. Hence, train schedules are closely coordinated with the local tidal cycles.

ATTACHMENT 3
GEOPHYSICAL SURVEYS

Two major geophysical surveys were made in order to assist in determining the nature and total thickness of the water-bearing formations.

Sparker Survey

The objective of the Sparker Survey was to determine the geologic features beneath the bay to a depth of about 1,000 feet. Because of the lack of subsurface geologic data in the area beneath the bay, the Sparker Survey provided the only practical means of gathering information about the nature of the underlying sediments.

The use of and results obtained from the Sparker Survey conducted in south San Francisco Bay are briefly described in Chapter III of this appendix. This attachment describes in detail the theory, field procedure, and equipment.

Theory

The Sparker Survey was considered to be a fast and relatively inexpensive method of obtaining extensive geologic information from beneath the waters of San Francisco Bay. This method is successful in showing buried structure beneath the floor of oceans and bays and is a technique used extensively by oil companies in their offshore operations. In principle, the Sparker Survey uses a low frequency spark as a source of seismic energy waves that are transmitted through the waters and the underlying sediments and then reflected back from layers of differing densities. These reflected energy waves are received by a floating hydrophone array towed behind the spark source and are recorded on a continuous-running electrically sensitive strip chart. The strip chart record represents a continuous picture of the layers in the subsurface along the selected traverse. When properly interpreted, this chart represents a geologic section.

A geologic discontinuity may be shown as an abrupt change or as a zone of very rapid change in acoustical properties. The physical condition causing the change may or may not be related to lithology, although reflecting interfaces usually are indicative of a change in the sediment type. Changes in sediment density or water content also could produce a reflecting interface, without an accompanying change in sediment material.

The acoustic impedance, Z, is expressed by the following equation:

$Z = PV$, where P is the density of the material and V is the velocity of the compressional waves through the medium.

The ratio of reflected energy to the incident energy at the interface is related to acoustic impedances of the two media by the following equation:

$$\frac{E_R}{E_i} \quad \frac{(P_2V_2 - P_1V_1)^2}{(P_2V_2 + P_1V_1)^2}$$ when the angle of incidence is 0 degrees.

The subscripts 1 and 2 refer to the different media. Thus, the amount of reflected energy depends upon the contrast in both the densities and velocities of sound in the respective layers.

In an ideal homogenous medium, the sound energy would emanate from a point source in the form of a spreading spherical wave. The acoustic energy arriving at any place in the medium would be proportional to the inverse square of the distance from the point source. Attenuation is also related to the physical characteristics of the transmitting medium. Thus, such things as absorption, dispersion, scattering, and diffraction affect the losses that an acoustic wave encounters while being propagated. In general, attenuation losses are frequency dependent; that is, high frequencies attenuate faster than low frequencies. Because of this, a low frequency sound source is used when deep sediment penetration is desirable.

The interpretation of the sparker records does not require the reading of multiple traces as in conventional reflection records. Because the record runs on a precise time basis, the width across the sparker record is constant and of known time duration. Hence, the depth to a particular horizon is the recorded time divided by two and multiplied by the velocity of sound along the path of transmission. Normally, scales are prepared for the average velocities for both water and sediments. For this project, a velocity of 6,000 ft/sec was selected. The scales provided on all profiles are based upon this number. The velocity of sound in water and mud was assumed to be 4,925 ft/sec. The occurrence of multiple reflections was found to be due to reverberations of sound between the bottom of sub-bottom layers and the water surface. Such repeated reflections may obscure the record so much that the first reflected arrival from a deep interface is masked. This condition was encountered in many areas of this survey.

Field Procedure

The Sparker Survey was conducted by Alpine Geophysical Associates, Inc., between May 9 and May 21, 1963. During this period, 110 miles of traverses were made on San Francisco Bay south of San Mateo Bridge. The traverse grid is shown in Figure 2.

The field procedure consisted of following the survey lines which had been plotted on hydrographic charts. Horizontal sextant angles on three fixed targets along the shore were taken at five minute intervals and plotted. A mark was made on the record with each fix, and the time and fix number plotted. This system was found to be accurate to within 100 feet. When traverses were along sloughs, the position was partially determined by recognizable features along the shores.

Equipment

Two power supply units were used. One was a 200-joule unit with standard water electrodes. This unit was used for deep penetration. Records for depths as great as 1,000 feet were obtained with this unit. For shallower but more detailed records, a 50-joule power supply unit was used. A brush electrode was used with this unit.

The size of the bubble pulse produced by the electrical discharge, along with frequencies produced, determine the resolution to which reflected horizons can be detected and measured. The brush electrode has a large number of small exposed wire ends which produce a number of small bubble pulses instead of the large one produced by the standard electrode. The time length of pulse with the brush electrode is about one-half the pulse length of the standard electrode, about one and one-half to two and one-half milliseconds in length. Layers two to three feet in thickness can be detected with this type of electrode.

The peak acoustic energy produced with the 200-joule power supply unit is between 250 and 600 cps. High frequency energy up to 5,000 cps is produced on the 50-joule power supply unit.

The detecting hydrophone array, called the eel, is composed of 10 Hall-Sears pressure sensitive geophones connected in series, with one-half wave length spacing between geophones, for a 500 cps signal source. This arrangement effectively attenuates horizontally propagated acoustic signals of around 500 cps, such as the direct water wave arrival from the sparker and boat generated noise. It also enhances the reflected acoustical energy, since the wave fronts from the vertically propagated reflected signals arrived at all geophones practically in phase (simultaneously). The geophones are encased in a pliable plastic tube which is filled with a solution of water and antifreeze and has both ends sealed. The long slender shape of the array makes for an easy, noise-free tow through the water. The output of the hydrophone array is connected to a preamplifier by means of a float supported, two conductor coaxial cable.

The output of the preamplifier is then fed to an electronic filter or directly by-passes the filter to the recorder amplifier. The filter is a variable band-pass type which can operate between 20 cycles and 200 kilocycles. The low and high band-passes are dialed directly on the front panel. The filter is an active type and has an insertion loss of one decibel within the

the pass band. The attenuation slope is 24 decibels per octave, and 12 decibels per octave at its cutoff frequency. Practically all of the survey records on this project were made without the filter in the circuit.

A nine-inch facsimile-type helical recorder prints the output of the system across the width of a continuously advancing electrosensitive paper strip. Interchangeable drive gears attached to the helix of the recorder make it possible to rotate the recorder at eight, four, and two revolutions per second, representing depths of approximately 300, 600, and 1,200 feet. The sparker is triggered by a contact that closes at the beginning of each helix revolution. The recorder amplifier raises the signal level and rectifies it to direct current for direct printing on the electrically sensitized recording paper. Exact timing on the helix is maintained by a 1,000 cps fork-controlled power supply driving a 1,000 cps synchronous helix drive motor.

All electronic equipment operates with a 120-volt 60-cycle alternating current supply with the exception of the pre-amplifier which has a self-contained battery. A five kilowatt gasoline-driven generator aboard the survey vessel supplied the electric power. This was later replaced by a 10 kilowatt unit, after failure of the smaller generator.

Gravity

The gravity survey was conducted during June 1964. The object of the survey was to show the depth and configuration of the buried bedrock surface beneath the area east and south of San Francisco Bay.

Theory

Gravity anomalies are caused by density contrasts in the rocks of the crust of the earth. In the South Bay area, there are three subsurface units, each having a different average density. Because of these differences in density, gravity anomalies result where there is a lateral change from one subsurface unit to another. Anomalies also result from a marked increase or decrease in thickness of one unit with relation to another.

There are several possible geologic interpretations which would satisfy the gravity anomalies in the south San Francisco Bay area. The interpretations given here are the most reasonable, considering all geologic data developed.

Analysis of the gravity data supports the assumption that the structural features in the South Bay area are controlled by a complex system of northwest-trending faults. Franciscan rocks underlie all of the younger sediments, but the anomalies indicate that the thickness of cover varies considerably from one fault block to the next. This suggests that there has been substantial vertical movement along these faults.

Field Procedure

The survey was conducted east of the bay in the area bounded by the San Mateo Bridge on the northwest, Agnew on the southeast, the Nimitz Freeway on the northeast, and the Bayshore Freeway on the southwest. Over 300 gravity stations were occupied with a station spacing of from one-half to one mile.

The gravity survey covered only a portion of the South Bay area. However, in order to properly interpret the geophysical data, the gravity field in the entire region had to be considered. Therefore, a comprehensive map was developed which incorporated data from earlier gravity surveys, particularly in the southern and southwestern parts of the area and across the San Mateo and Dumbarton Bridges. The completed map, which includes both reconnaissance and detailed work, covers the area from the San Mateo Bridge, on the northwest, to the San Jose area on the southeast, and from the foothills on the southwest side of the bay to the foothills on the northeastern side. This map is presented as Plate 8.

Some of the stations occupied were bench marks established by city, county and federal agencies. Most station locations and all station elevations were surveyed by the Department of Water Resources.

Previous Work. A gravity map with interpretation of the geology of the south San Francisco Bay area was completed by Taylor[30/] based on a few widely spaced profiles. Additional gravity data for the San Francisco Peninsula area, and a traverse across the San Mateo Bridge, were completed by Greve.[19/] Parts of these data were incorporated into the present investigation.

Density Measurements. Measurements of the densities of the rocks from the San Francisco Bay area were reported on by both Taylor and Greve. A density of 2.67 gm/cc was found to be the average for all rocks of the Franciscan Formation. The density ranged from 2.53 gm/cc for serpentine, to 2.90 gm/cc for greenstone.

Taylor determined an average density of 2.41 gm/cc for a composite group of Cretaceous, Tertiary, and Plio-Pleistocene rocks. Greve found an average density of 2.22 gm/cc for Tertiary rocks from the Half Moon Bay area.

Density data on Upper Quaternary alluvium, reported on by Trask and Rolston,[34/] indicate an average density of 1.90 gm/cc for these Recent and Upper Pleistocene deposits.

Because certain assumptions must be made in order to evaluate the gravity data, Taylor proposed dividing the rocks in the south San Francisco Bay area into three general divisions according to density: the Franciscan Formation (2.67 gm/cc), the Cretaceous-Tertiary-Plio-Pleistocene sediments (2.41 gm/cc), and the Upper Quaternary alluvium (1.90 gm/cc). These divisions and values were adopted for the present study, with the exception that an average of the values given by both Taylor and Greve was used for the middle unit. This average value was 2.32 gm/cc.

Gravity Measurements. In order to provide good control for the gravity survey, a network of local base stations was established in the survey area. Stations were established at bench marks in Alviso, Albrae siding, Newark, and Alvarado. This network was tied to the California Division of Mines and Geology gravity control stations at Sunnyvale and Moffett Field. These, in turn, are tied to the national base station in Washington, D.C. through a station at the San Francisco International Airport, as reported by Behrendt and Woollard.[3/]

Stations occupied included U.S. Coast and Geodetic Survey and U.S. Geological Survey bench marks and points established for this project. Elevations of most of the stations were surveyed to the nearest 0.1 foot by the Department. Because of active land subsidence in parts of the area, all stations, including bench marks were tied to those bench marks believed to be on relatively stable ground.

Gravity Reductions. The values of observed gravity were reduced to sea level datum by applying normal elevation and Bouguer corrections. The data were reduced for two densities: 2.67 (0.05998 milligals per foot), a figure commonly used for regional studies; and 2.00 (0.06854 milligals per foot), which is very nearly the density of bay mud. Because the range of elevation differences is small and all stations in the detailed survey are close to sea level, there is very little difference in the results obtained by using the two different density values. Simple Bouguer anomalies were determined by subtracting theoretical sea level gravity for the latitude of the stations from the reduced observed gravity values.

No terrain corrections were applied to the data in the detailed survey because this correction is negligible for most of the area. Taylor and Greve had already made these corrections to their data from many of their stations.

The data derived by Taylor had to be adjusted for a difference in base value and in the calibration of the two different meters used for the surveys. This was done by reoccupying of 15 stations used by Taylor.

Equipment

Worden gravity meter number 558, with a scale constant of 0.09774 milligals per scale division, was used for the survey.

Drift of the gravity meter, caused chiefly by changes in temperature and earth tides, was controlled by reading the meter on a base station at intervals during the day not usually exceeding two hours.

Interpretation. In order to facilitate interpretation of the gravity data, four northeast-trending gravity profiles, shown on Plate 9, were prepared. Residual anomalies were determined by including the regional gravity trend on each profile. The slope of the regional trend is based on gravity values obtained on or near exposures of Franciscan basement rocks. This regional trend indicates what the gravity values would be if the entire area were underlain at the ground surface by Franciscan rocks having a density of 2.67 gm/cc. Anomalies are indicated on the profiles by deviations of the observed gravity from the regional trends.

Because anomalies in the San Francisco Bay area are caused mostly by northwest-trending features, a two-dimensional gravity graticule method of analysis was used as outlined by Dobrin.[18] Utilizing this method, the assumed density contrasts and the residual anomalies, geologic cross-sections showing density units were constructed for each profile. Because alternative geologic solutions are possible, precise agreement between the geologic and geophysical data was attempted. The solutions obtained were of the proper order of magnitude to match the field gravity anomalies. The four gravity profiles are shown on Plate 9.

Profile A-A' begins south of Coyote Point and passes northeastward along the line of gravity stations across the San Mateo-Hayward Bridge to a point south of Hayward.

Rocks of the Franciscan Formation are exposed near the western end of this profile. The gravity data indicate a relatively shallow alluvial fill that gradually increases in depth to the northeast. Near the west end of the bridge, a small gravity high suggests a possible buried ridge of Franciscan rocks. However, a calculated depth of about 400 to 500 feet does not agree with data from two drill holes, located just south of this profile, which are reported to have encountered Franciscan rocks at depths of 80 and 164 feet. Assuming the drill hole data are correct, this lack of agreement could be caused either by incomplete data in this area or because the Franciscan rocks have a lower than average density. Some evidence to support the gravity interpretation is given by Greve[19/] who analyzed a magnetic anomaly, probably caused by Franciscan serpentine, near the west end of the bridge. He concluded that the Franciscan rocks were about 600 feet below the ground surface at this locality.

East of the west end of the bridge, the anomaly becomes increasingly negative. Two zones of relatively steep gradients are interpreted as possible faults. As shown on the profile, the blocks on the northeastern sides of both of these faults have evidently moved downward. A steep upward gravity gradient on the extreme eastern end of the profile may also represent a fault. As shown on Profile A-A', this fault may define the northeastern side of a graben located between the center of the bay and the eastern end of the profile. The maximum thickness of the sediments overlying the Franciscan basement along this profile is estimated to be about 3,000 feet.

Profile B-B' begins near Woodside, crosses the bay in a northeastward direction along Dumbarton Bridge, passes the southeastern tip of Coyote Hills, and terminates at a point near Niles.

Proceeding eastward from the west end of the profile, the first fault shown on the section corresponds to a reverse fault mapped by Dibblee.[16/] This fault separates Franciscan rocks on the west, from younger sediments to the east. Just east of the fault, the interpretation of the negative anomaly indicates a thickness of about 1,500 feet of Tertiary-Quaternary rocks.

Toward the east, a rise in the profile in the vicinity of Atherton suggests that the Franciscan Formation has been elevated, and possible faults are shown on each side of this block. The geologic interpretation indicates that Franciscan rocks should be found at a depth of about 500 feet in this part of Atherton and Menlo Park. The gravity low located immediately to the east might represent either a small graben, as shown on the section, or a buried valley. The relatively steep gradients on each side suggest faults.

Farther east along the profile, both Coyote Hills and Dumbarton Point are marked with gravity highs. Exposed Franciscan rocks, including a large proportion of volcanics, explain the Coyote Hills anomaly. The Dumbarton Point anomaly is probably also a part of the same uplifted Franciscan block. Data indicate Franciscan rocks should be present here at a depth of perhaps less than 200 feet.

About a mile and a half east of Coyote Hills, near Newark, the gravity profile steepens downward. This may mark the position of the northern extension of the Silver Creek fault, as proposed by Taylor.[30] The section of younger rocks shown east of this fault has an average thickness of about 1,400 feet. These rocks continue to the end of the profile, where they are exposed in the hills.

There is evidence for steeply-dipping discontinuities, perhaps measuring some hundreds of feet, along the Hayward and Mission faults, and possibly another fault located about one-half mile west of the Hayward fault on this profile.

<u>Profile C-C'</u> begins at a point west of Los Altos Hills, passes northeastward through Moffett Field and across the southern end of the bay and terminates at a point north of Warm Springs.

Just west of Los Altos Hills the profile crosses two reverse faults, the easternmost of which forms the boundary between the Franciscan Formation and the Santa Clara Formation. In order to account for the 20-milligal negative anomaly in this area, a thick section of low density rocks must be present. Consequently, a graben of Tertiary-Quaternary rocks, downdropped about 4,500 feet, is shown on the section. The northeastern boundary of this downdropped block is probably a fault which brings the Franciscan rocks to within 2,000 feet of the ground surface near Mountain View, to within 1,200 feet at the north end of Moffett Field, and to within about 600 feet near the confluence of Alviso Slough and Coyote Creek.

East of Menlo Park, there is a gravity low which may represent a small graben. Faults are shown on each side of this structure, but the displacement along the southwestern fault is very small and may be dying out in a southeasterly direction.

A short distance northeast of Coyote Creek there is a sharp drop in the profile which may represent a steep contact with a section of younger rocks to the east. As in Profile B-B' this may represent the extension of the Silver Creek fault. A steepening of the gradient indicates the possibility of a second fault near the eastern end of the profile. The total thickness of younger sediments shown on this part of the geologic section, where the anomaly approaches 20 milligals, is about 3,800 feet.

Profile D-D' begins southwest of Los Altos, passes northeastward through Sunnyvale and Alviso, and ends at a point at the edge of the foothills midway between Warm Springs and Milpitas.

As in Profile C-C', this profile crosses two reverse faults which separate the Franciscan Formation from Santa Clara Formation and the alluvium. On this profile, a negative anomaly of about 24 milligals is centered near Fremont Avenue in Los Altos and is interpreted to represent a section of about 5,600 feet of Tertiary-Quaternary rocks. This graben is bounded on the east by two possible faults, one in Mountain View near the point where the profile crosses El Camino Real and the other in Sunnyvale where the profile crosses Bayshore Freeway. There is an uplifted block between Mountain View and a point north of Alviso, where a drop in the gravity profile suggests the presence of another high angle fault. The highest point of Franciscan basement rock is indicated by the positive anomaly located slightly more than a mile northeast of the junction of the Mountain View-Alviso Road and Bayshore Freeway. Basement rock at this high, called the Moffett Field-Oak Hill high is believed to be at a depth of about 1,400 feet.

Two possible faults, which form the western boundary of a graben, are indicated north and northeast of Alviso. A maximum thickness of about 5,600 feet of younger sediments is attained south of Warm Springs, where the anomaly is about -26 milligals.

At the northeastern end of the profile, north of Milpitas and near the projected Hayward fault, the profile rises, suggesting an uplift in the basement rocks. However, data are insufficient to delineate the entire anomaly.

Results. Plate 3 shows the location of faults inferred from gravity data and approximate depth contours on the top of the Franciscan Formation for the portion of the area where the greatest detail is available. Also shown are depths to Franciscan bedrock as reported on water well logs.

Except for the area near the western end of the San Mateo Bridge, where gravity data indicate an excessive thickness of younger sediments, the contour data agree reasonably well with the limited depth information available.

The greatest thicknesses of younger rocks are evidently represented by the Cupertino low, the Niles-Evergreen low, and the low north of Coyote Hills. In the Cupertino low, the data indicate a total thickness of more than 5,000 feet of younger sediments near Mountain View, and probably considerably more east of Cupertino. The Niles-Evergreen low suggests more than 5,000 feet of younger rocks near Warm Springs, and perhaps more than 7,000 feet southeast of Milpitas. The low north of Coyote Hills probably represents a thickness of about 3,000 feet of these rocks.

The Franciscan basement rocks crop out in the hills on both sides of the bay, at Oak Hill southeast of San Jose, in San Mateo and Redwood City, and in the Coyote Hills. The gravity data reveal that these rocks should also be found within about 200 feet of the surface at Dumbarton Point, about 1,200 feet at Moffett Field, and about 600 feet in the vicinity of Alvarado. Between the Coyote Hills and Alviso, the depth to Franciscan rocks gradually increases. Calculated depths to bedrock range from 0 at the Coyote Hills to 600 feet at Coyote Slough and 1,000 feet at Alviso.

Because the density values of the Santa Clara Formation are very similar to those of the Tertiary and Cretaceous sediments, gravity methods will not show a distinction between these formations.

The gravity data indicate the presence of several buried faults in the south San Francisco Bay area. These are shown on Plate 3, and include the Silver Creek fault, the Hayward fault, and a number of unnamed faults. The Silver Creek fault can be traced from near Evergreen northwestward to the northeastern end of Coyote Hills, where the data indicate that the fault may die out. Plate 3 shows only one fault rather than the two branches suggested by Taylor.[30] This fault separates a thick prism of younger sediments on the northeast from Franciscan bedrock on the southwest. The Hayward fault is located along the edge of the foothills on the eastern side of a downdropped block of younger sediments. The area of this fault was not covered by the gravity survey except near Niles, where the data suggest some vertical movement along the fault.

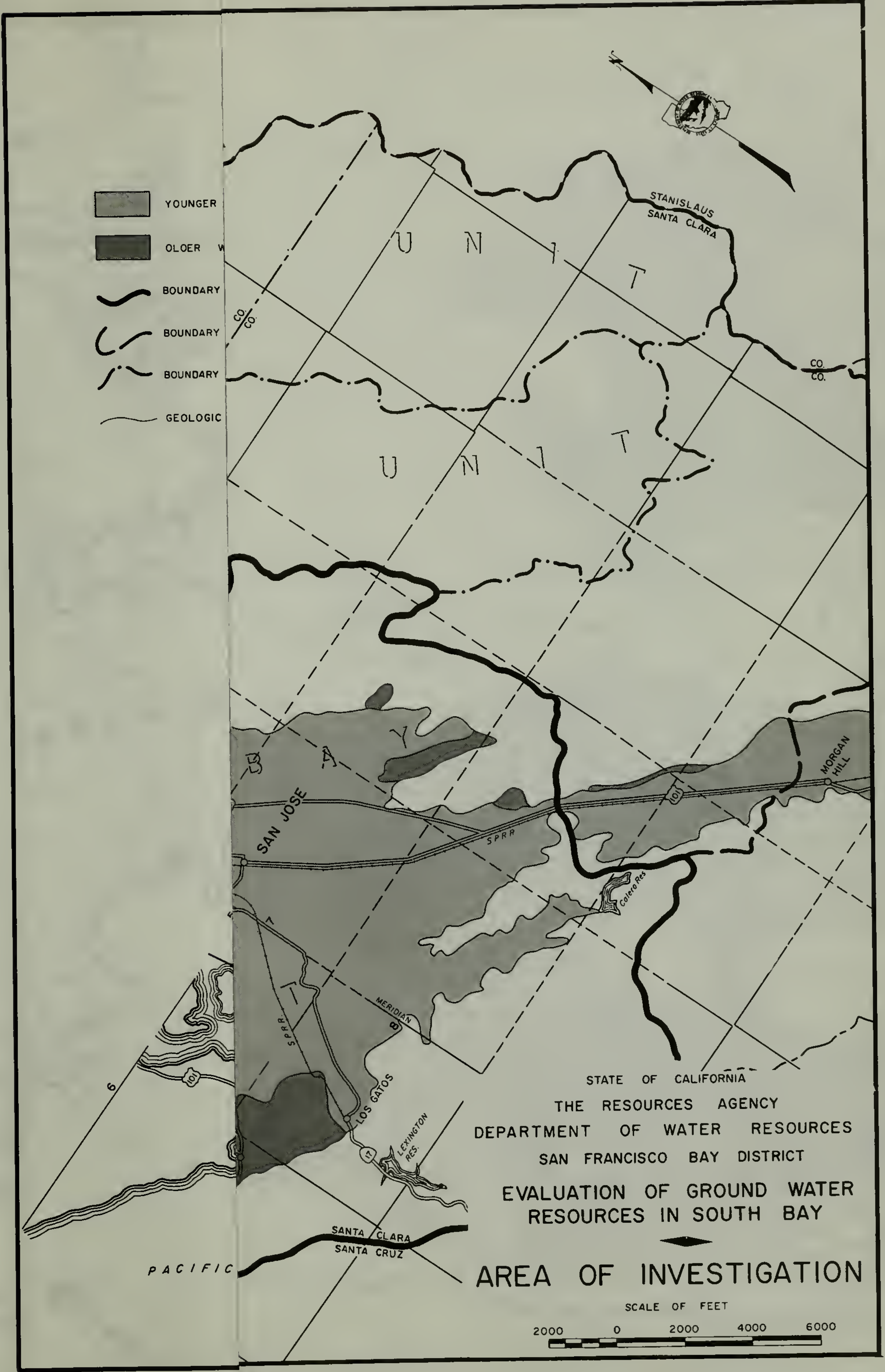
Several faults mapped by Dibblee appear to mark the southwestern boundary of a thick wedge of younger sediments in the area between Palo Alto and Cupertino. These faults correspond in part to the Shannon fault, described by Taylor, but Dibblee has mapped them as reverse faults, an interpretation that is confirmed by the gravity data.

Taylor named the Stanford fault as forming the northeastern boundary of a graben in this area. The location of this fault was based on widely separated gravity profiles from Palo Alto to San Jose. However, new data by Greve[19] and the present gravity survey in Sunnyvale and Mountain View tend to cast some doubt on the position of portions of this fault. In both of these areas the fault, as shown by Taylor, appears to cross some of the buried structural features. In view of new data, it is probably more reasonable to assume two separate, nearly parallel faults, as shown on Plate 3. One fault extends southeastward from Redwood City to Mountain View, where it becomes obscure in the vicinity of the Cupertino low. The other forms the southwestern boundary of the high which passes through Moffett Field. The latter fault might extend southeasterly to Oak Hill, near San Jose. The northwestern portion of the fault may extend at least as far as Dumbarton Point.

Other possible faults shown on Plate 3 include one on the northeastern side of the Redwood City-Palo Alto high. This fault is approximately parallel to Bayshore Freeway in Palo Alto, but may die out near Adobe Creek. To the northwest, this fault may extend as far as the area east of Coyote Point, but data are too meager to permit a reliable analysis.

The abrupt termination, or sharp bend toward the northeast of the northern extension of the Coyote Hills anomaly, north of Alameda Creek, suggests the possibility of a northeast-trending fault in this area. This fault may offset the northern subsurface extension of the Coyote Hills.

Another possible fault is an offshoot of the Silver Creek fault. This offshoot trends west of north and passes close to Agnew and thence to the west of Warm Springs, where it approaches the Hayward fault. This offshoot fault may be the western boundary of the graben represented by the Niles-Cupertino low.


YOUNGER
OLDER W
BOUNDARY
BOUNDARY
BOUNDARY
GEOLOGIC
STANISLAUS
SANTA CLARA
CO.
CO.
UNIT
UNIT
BAY
SAN JOSE
SPRR
101
MORGAN HILL
Calero Res
MERIDIAN
SPRR
LOS GATOS
17
LEXINGTON RES.
6
101
SANTA CLARA
SANTA CRUZ
PACIFIC
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER RESOURCES IN SOUTH BAY
AREA OF INVESTIGATION
SCALE OF FEET
2000 0 2000 4000 6000

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES IN SOUTH BAY

AREA OF INVESTIGATION

SCALE OF FEET
2000 0 2000 4000 6000


SANTA TERESA PLAIN
COYOTE PLAIN
GREEN ALLUVIAL APRON
ALAMITOS ALLUVIAL APRON
APRON
HIGHLAND
SANTA TERESA HILLS
OAK HILL
EDENVALE RIDGE
EDENVALE GAP
COYOTE GORGE
COYOTE NARROWS
Coyote Creek
Silver Creek
Dry Creek
Canoas Cr
Arroyo Calero
Alamitos Cr
Guadalupe River
Guadalupe Res
Calero Res
Lake Chabot
ALMADEN EXPRESSWAY
TULLY RD
KING RD
FOOTHILL
SKYLINE
COYOTE POINT
SAN MATE
LEGEND
SANTA CLARA FORMATION (PLIO-PLEISTOCENE AGE)
BOUNDARIES OF PHYSIOGRAPHIC FEATURES
DRAINAGE UNIT BOUNDARY
80 TOPOGRAPHIC CONTOURS
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER RESOURCES
SOUTH BAY
PHYSIOGRAPHIC FEATURES
SCALE OF MILES
0 1 2 3

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES
SOUTH BAY

PHYSIOGRAPHIC FEATURES

PLATE 2


DIABLO HIGHLAND
DIABLO HIGHLAND
SAN LEANDRO CONE
DRY CREEK CONE
NILES CONE
MISSION ALLUVIAL APRON
MISSION UPLAND
WARM SPRINGS ALLUVIAL APRON
BERRYESSA ALLUVIAL APRON
EVERGREEN ALLUVIAL APRON
BAY PLAIN
BAY PLAIN
BAY PLAIN
SAN JOSE PLAIN
COYOTE PLAIN
SANTA TERESA PLAIN
ALAMITOS ALLUVIAL APRON
WEST SIDE ALLUVIAL APRON
SAN FRANCISQUITO CONE
SAN MATEO ALLUVIAL APRON
SAN MATEO UPLAND
SARATOGA UPLAND
SANTA CRUZ
HIGHLAND
SAN FRANCISCO BAY
DUMBARTON STRAIT
MOFFETT FIELD
ALAMEDA COUNTY
SAN MATEO COUNTY
LEGEND
SANTA CLARA FORMATION (PLIO-PLEISTOCENE AGE)
BOUNDARIES OF PHYSIOGRAPHIC FEATURES
DRAINAGE UNIT BOUNDARY
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SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER RESOURCES
SOUTH BAY
PHYSIOGRAPHIC FEATURES
SCALE OF MILES
0 1 2 3

LEGEND

QUATERNARY

- RECENT
  - Qls — LANDSLIDES
  - Qm — ALLUVIUM MARSHLAND DEPOSITS: UNCONSOLIDATED, CONSISTING CHIEFLY OF CLAY WITH IRREGULAR LENSES OF SAND AND GRAVEL
  - Qs — ALLUVIUM STREAM DEPOSITS: UNCONSOLIDATED, CONSISTING OF GRAVEL, SAND, SILT, AND CLAY
- PLEISTOCENE
  - TQ — SANTA CLARA FORMATION: UNCONSOLIDATED TO SEMICONSOLIDATED CONTINENTAL DEPOSITS OF GRAVEL, SAND, SILT, AND CLAY. INCLUDES EXPOSURES OF PACKWOOD GRAVELS

TERTIARY

- PLIOCENE
  - Tpr — LEONA AND ALUM ROCK RHYOLITE: FLOWS AND INTRUSIVE DOMES
  - Tp — UNDIFFERENTIATED PLIOCENE FORMATIONS: CONTINENTAL AND MARINE SANDSTONE, SILTSTONE, AND CONGLOMERATE. SOME TUFF AND LIMESTONE
- MIOCENE
  - Tm — UNDIFFERENTIATED MIOCENE FORMATIONS: MARINE SANDSTONE, SHALE, AND CONGLOMERATE. ALSO VOLCANIC ROCKS
- OLIGOCENE
  - To — UNDIFFERENTIATED OLIGOCENE FORMATIONS: MARINE SANDSTONE AND SILTSTONE
- EOCENE
  - Te — UNDIFFERENTIATED EOCENE FORMATIONS: MARINE SANDSTONE, CLAY, AND SHALE. SOME CONGLOMERATE BEDS

CRETACEOUS

- K — UNDIFFERENTIATED CRETACEOUS FORMATIONS: MARINE SANDSTONE, SILTSTONE, SHALE, AND CONGLOMERATE
- sp — SERPENTINE AND ASSOCIATED SILICA CARBONATE ROCKS: ALTERED AND SHEARED ULTRABASIC ROCKS

JURASSIC

- J — UNDIFFERENTIATED KNOXVILLE FORMATION AND FRANCISCAN GROUP: MARINE SANDSTONE, SHALE, AND CHERT WITH SOME CONGLOMERATE AND LIMESTONE LENTILS

SYMBOLS

- FAULT, DASHED WHERE APPROXIMATELY LOCATED. U - UPTHROWN SIDE, D - DOWNTHROWN SIDE. ARROWS SHOW RELATIVE DIRECTION OF HORIZONTAL MOVEMENT).
- CONCEALED FAULT
- BURIED FAULT IN FRANCISCAN GROUP ROCKS (U - UPTHROWN SIDE, D - DOWNTHROWN SIDE) QUERIED WHERE EXTENSION UNCERTAIN)
- AXIS OF ANTICLINE, (DASHED WHERE APPROXIMATELY LOCATED) SHOWING PLUNGE
- AXIS OF SYNCLINE (DASHED WHERE APPROXIMATELY LOCATED) SHOWING PLUNGE
- AXIS OF OVERTURNED ANTICLINE, SHOWING PLUNGE
- AXIS OF OVERTURNED SYNCLINE, SHOWING PLUNGE
- LITHOLOGIC CONTACT, LOCATION APPROXIMATE
- -3500 — CONTOUR ON BURIED SURFACE OF FRANCISCAN GROUP ROCKS. ELEVATIONS ARE SUBSEA
- 600 — WELL SHOWING DEPTH TO NONWATER BEARING ROCKS OF THE FRANCISCAN GROUP

AREAL GEOLOGY

LEGEND

QUATERNARY — RECENT, PLEISTOCENE

- Qls — LANDSLIDES
- Qm — ALLUVIUM - MARSHLAND DEPOSITS
  UNCONSOLIDATED, CONSISTING CHIEFLY OF CLAY WITH IRREGULAR LENSES OF SAND AND GRAVEL
- Qs — ALLUVIUM STREAM DEPOSITS
  UNCONSOLIDATED, CONSISTING OF GRAVEL, SAND, SILT, AND CLAY
- TQ — SANTA CLARA FORMATION
  UNCONSOLIDATED TO SEMICONSOLIDATED CONTINENTAL DEPOSITS OF GRAVEL, SAND, SILT, AND CLAY INCLUDES EXPOSURES OF PACKWOOD GRAVELS

TERTIARY — PLIOCENE, MIOCENE, OLIGOCENE, EOCENE

- Tpr — LEONA AND ALUM ROCK RHYOLITE
  FLOWS AND INTRUSIVE DOMES
- Tp — UNDIFFERENTIATED PLIOCENE FORMATIONS
  CONTINENTAL AND MARINE SANDSTONE, SILTSTONE, AND CONGLOMERATE SOME TUFF AND LIMESTONE
- Tm — UNDIFFERENTIATED MIOCENE FORMATIONS
  MARINE SANDSTONE, SHALE, AND CONGLOMERATE ALSO VOLCANIC ROCKS
- To — UNDIFFERENTIATED OLIGOCENE FORMATIONS
  MARINE SANDSTONE AND SILTSTONE
- Te — UNDIFFERENTIATED EOCENE FORMATIONS
  MARINE SANDSTONE, CLAY, AND SHALE SOME CONGLOMERATE BEDS

CRETACEOUS

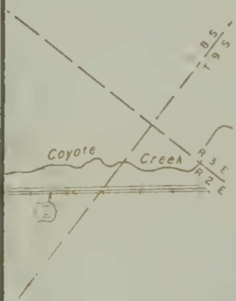
- K — UNDIFFERENTIATED CRETACEOUS FORMATIONS
  MARINE SANDSTONE, SILTSTONE, SHALE, AND CONGLOMERATE
- sp — SERPENTINE AND ASSOCIATED SILICA CARBONATE ROCKS
  ALTERED AND SHEARED ULTRABASIC ROCKS

JURASSIC

- J — UNDIFFERENTIATED KNOXVILLE FORMATION AND FRANCISCAN GROUP
  MARINE SANDSTONE, SHALE, AND CHERT WITH SOME CONGLOMERATE AND LIMESTONE LENTILS

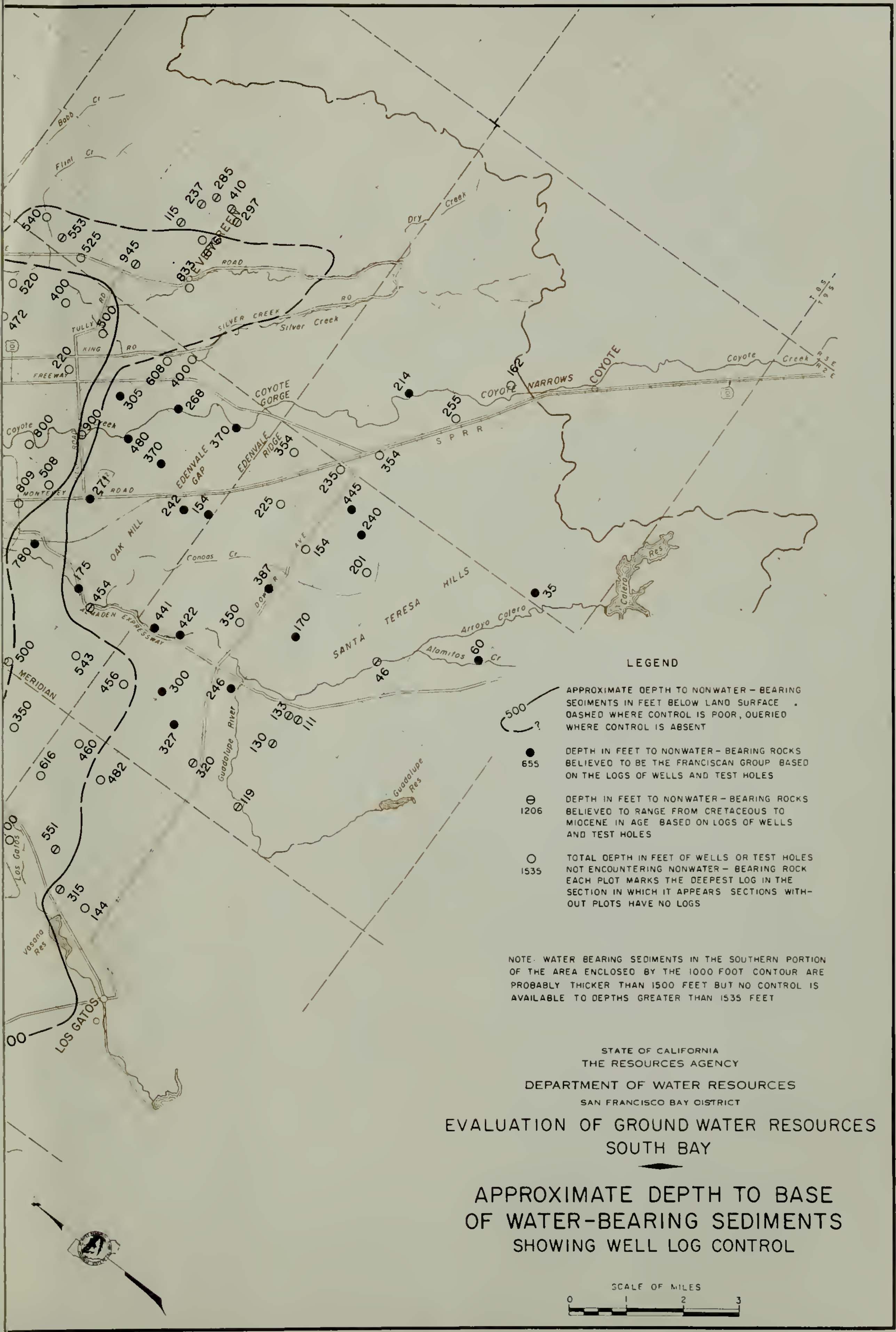
SYMBOLS

- FAULT DASHED WHERE APPROXIMATELY LOCATED
  U - UPTHROWN SIDE D DOWNTHROWN SIDE
  ARROWS SHOW RELATIVE DIRECTION OF HORIZONTAL MOVEMENT).
- CONCEALED FAULT
- BURIED FAULT IN FRANCISCAN GROUP ROCKS (U - UPTHROWN SIDE D DOWNTHROWN SIDE QUERIED WHERE EXTENSION UNCERTAIN)
- AXIS OF ANTICLINE, (DASHED WHERE APPROXIMATELY LOCATED) SHOWING PLUNGE
- AXIS OF SYNCLINE, (DASHED WHERE APPROXIMATELY LOCATED) SHOWING PLUNGE
- AXIS OF OVERTURNED ANTICLINE, SHOWING PLUNGE
- AXIS OF OVERTURNED SYNCLINE, SHOWING PLUNGE
- LITHOLOGIC CONTACT, LOCATION APPROXIMATE
- -3500 — CONTOUR ON BURIED SURFACE OF FRANCISCAN GROUP ROCKS ELEVATIONS ARE SUBSEA
- 600 — WELL SHOWING DEPTH TO NONWATER BEARING ROCKS OF THE FRANCISCAN GROUP



AREAL GEOLOGY


LEGEND
QUATERNARY
RECENT
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
TERTIARY
CRETACEOUS
JURASSIC
LANDSLIDES
ALLUVIUM MARSHLAND DEPOSITS
ALLUVIUM STREAM DEPOSITS
SANTA CLARA FORMATION
LEONA AND ALUM ROCK RHYOLITE
UNDIFFERENTIATED PLIOCENE FORMATIONS
UNDIFFERENTIATED MIOCENE FORMATIONS
UNDIFFERENTIATED OLIGOCENE FORMATIONS
UNDIFFERENTIATED EOCENE FORMATIONS
UNDIFFERENTIATED CRETACEOUS FORMATIONS
SERPENTINE AND ASSOCIATED SILICA CARBONATE ROCKS
FRANCISCAN GROUP
SYMBOLS
SOUTH BAY AREA
SOURCES OF GEOLOGY
HAYWARD
MT EDEN
CENTERVILLE
IRVINGTON
WARM SPRINGS
MILPITAS
SAN FRANCISCO BAY
DUMBARTON STRAIT
SAN JOSE
SANTA CLARA
SUNNYVALE
MOUNTAIN VIEW
PALO ALTO
REDWOOD CITY
CUPERTINO
CAMPBELL
ATHERTON
BELMONT
SILVER CREEK FAULT
HAYWARD FAULT
SAN ANDREAS FAULT
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER
RESOURCES — SOUTH BAY
AREAL GEOLOGY
SHOWING SUBSURFACE FEATURES
SCALE OF MILES
0
1
2
3



LEGEND

500 — ? APPROXIMATE DEPTH TO NONWATER - BEARING SEDIMENTS IN FEET BELOW LAND SURFACE. DASHED WHERE CONTROL IS POOR, QUERIED WHERE CONTROL IS ABSENT

● 655 DEPTH IN FEET TO NONWATER - BEARING ROCKS BELIEVED TO BE THE FRANCISCAN GROUP BASED ON THE LOGS OF WELLS AND TEST HOLES

⊖ 1206 DEPTH IN FEET TO NONWATER - BEARING ROCKS BELIEVED TO RANGE FROM CRETACEOUS TO MIOCENE IN AGE BASED ON LOGS OF WELLS AND TEST HOLES

○ 1535 TOTAL DEPTH IN FEET OF WELLS OR TEST HOLES NOT ENCOUNTERING NONWATER - BEARING ROCK EACH PLOT MARKS THE DEEPEST LOG IN THE SECTION IN WHICH IT APPEARS SECTIONS WITHOUT PLOTS HAVE NO LOGS

NOTE: WATER BEARING SEDIMENTS IN THE SOUTHERN PORTION OF THE AREA ENCLOSED BY THE 1000 FOOT CONTOUR ARE PROBABLY THICKER THAN 1500 FEET BUT NO CONTROL IS AVAILABLE TO DEPTHS GREATER THAN 1535 FEET

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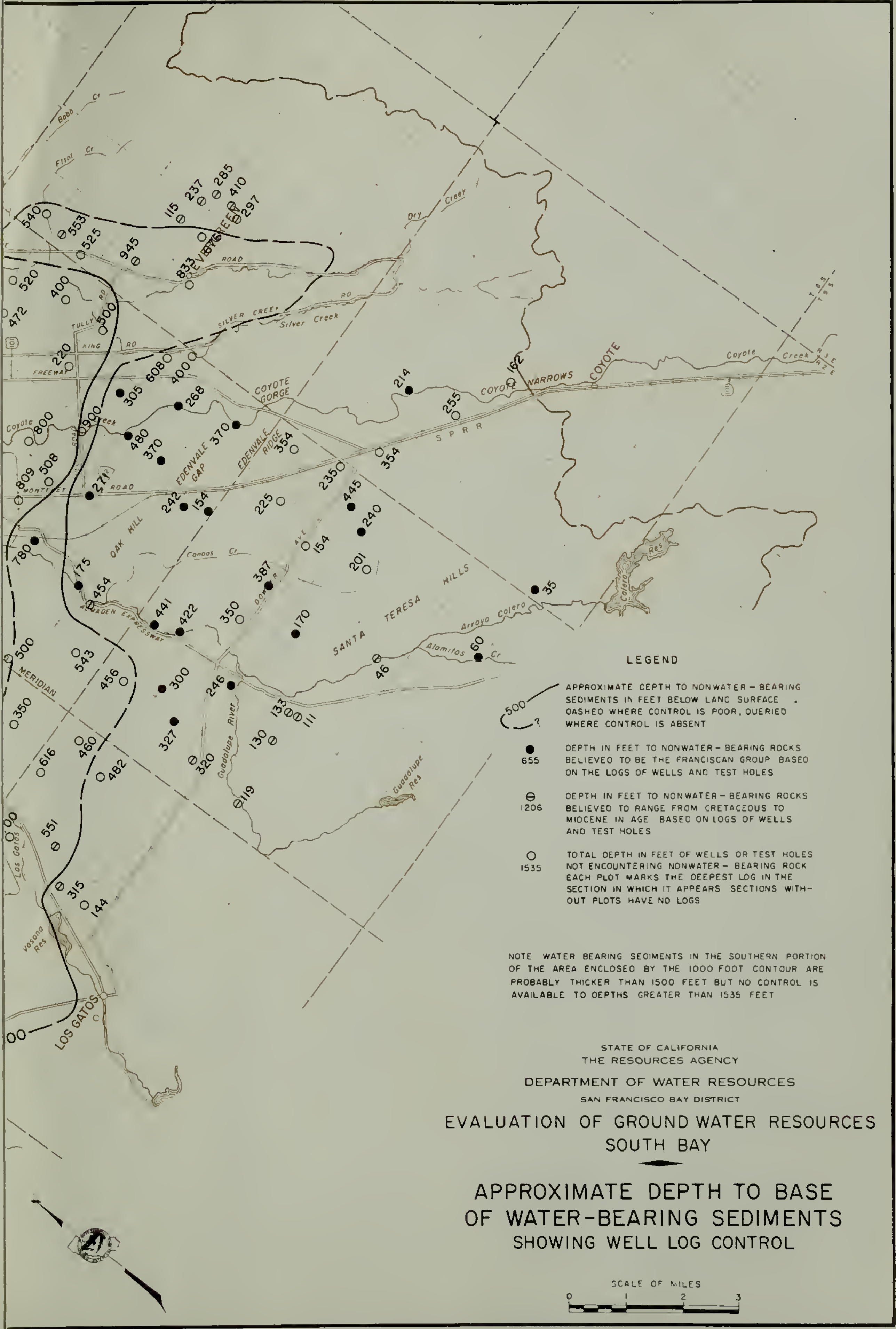
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES
SOUTH BAY

APPROXIMATE DEPTH TO BASE OF WATER-BEARING SEDIMENTS
SHOWING WELL LOG CONTROL

SCALE OF MILES
0 1 2 3



LEGEND

500 — APPROXIMATE DEPTH TO NONWATER-BEARING SEDIMENTS IN FEET BELOW LAND SURFACE. DASHED WHERE CONTROL IS POOR, QUERIED WHERE CONTROL IS ABSENT

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STATE OF CALIFORNIA
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DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES
SOUTH BAY

APPROXIMATE DEPTH TO BASE OF WATER-BEARING SEDIMENTS
SHOWING WELL LOG CONTROL

SCALE OF MILES
0 1 2 3


SAN FRANCISCO BAY
ALAMEDA COUNTY
SAN MATEO COUNTY
HAYWARD
MT. EDEN
ALVARADO
NILES
CENTERVILLE
IRVINGTON
MISSION SAN JOSE
WARM SPRINGS
NEWARK
MILPITAS
ALVISO
DUMBARTON STRAIT
MOFFETT FIELD
MOUNTAIN VIEW
SUNNYVALE
SANTA CLARA
SAN JOSE
CAMPBELL
CUPERTINO
SARATOGA
LOS GATOS
LOS ALTOS
LOS ALTOS HILLS
PALO ALTO
MENLO PARK
ATHERTON
REDWOOD CITY
BELMONT
SAN MATEO
WOODSIDE
COYOTE NARROWS
COYOTE
SANTA TERESA HILLS
LEGEND
APPROXIMATE DEPTH TO NONWATER - BEARING SEDIMENTS IN FEET BELOW LAND SURFACE. DASHED WHERE CONTROL IS POOR, QUERIED WHERE CONTROL IS ABSENT
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STATE OF CALIFORNIA
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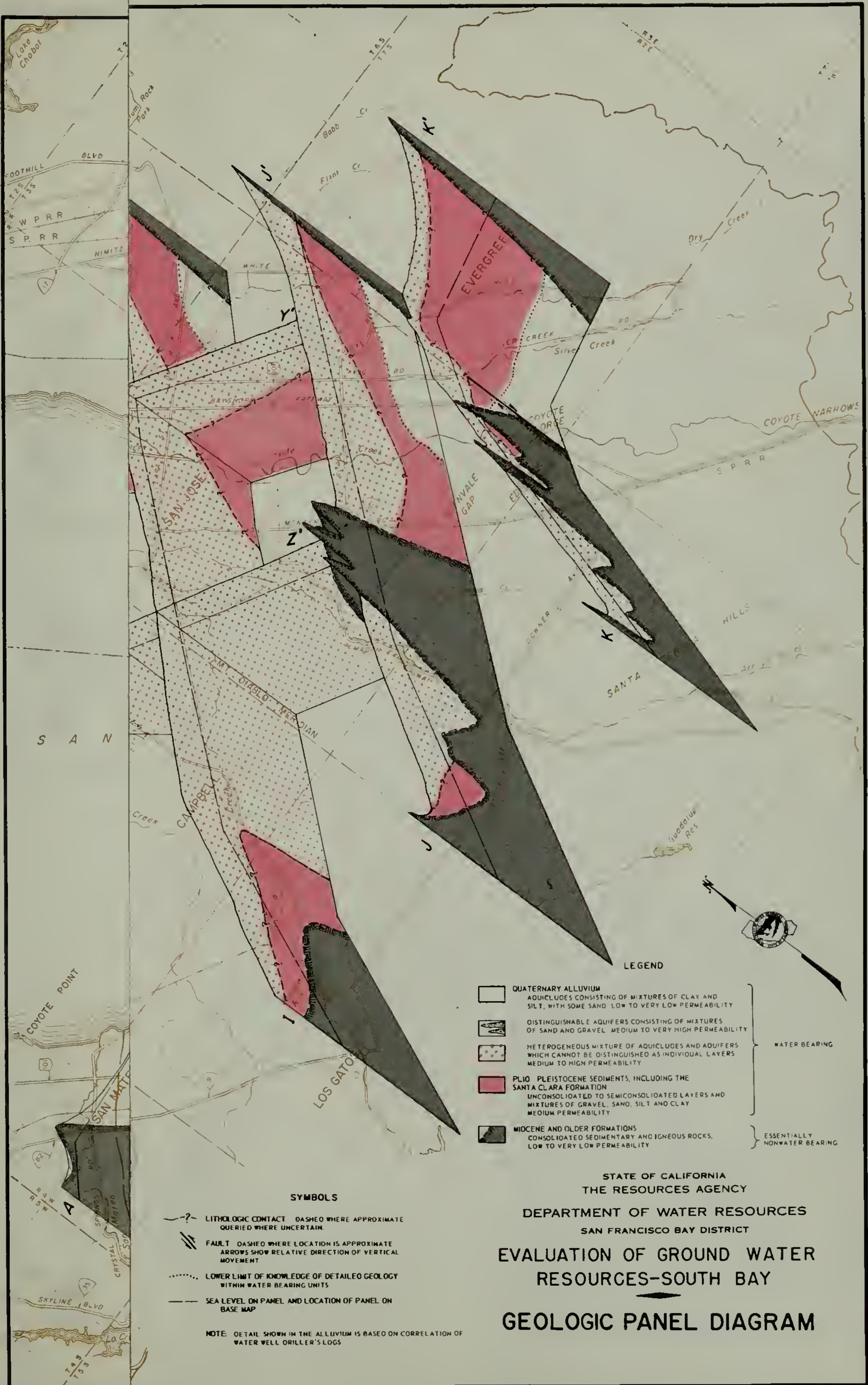
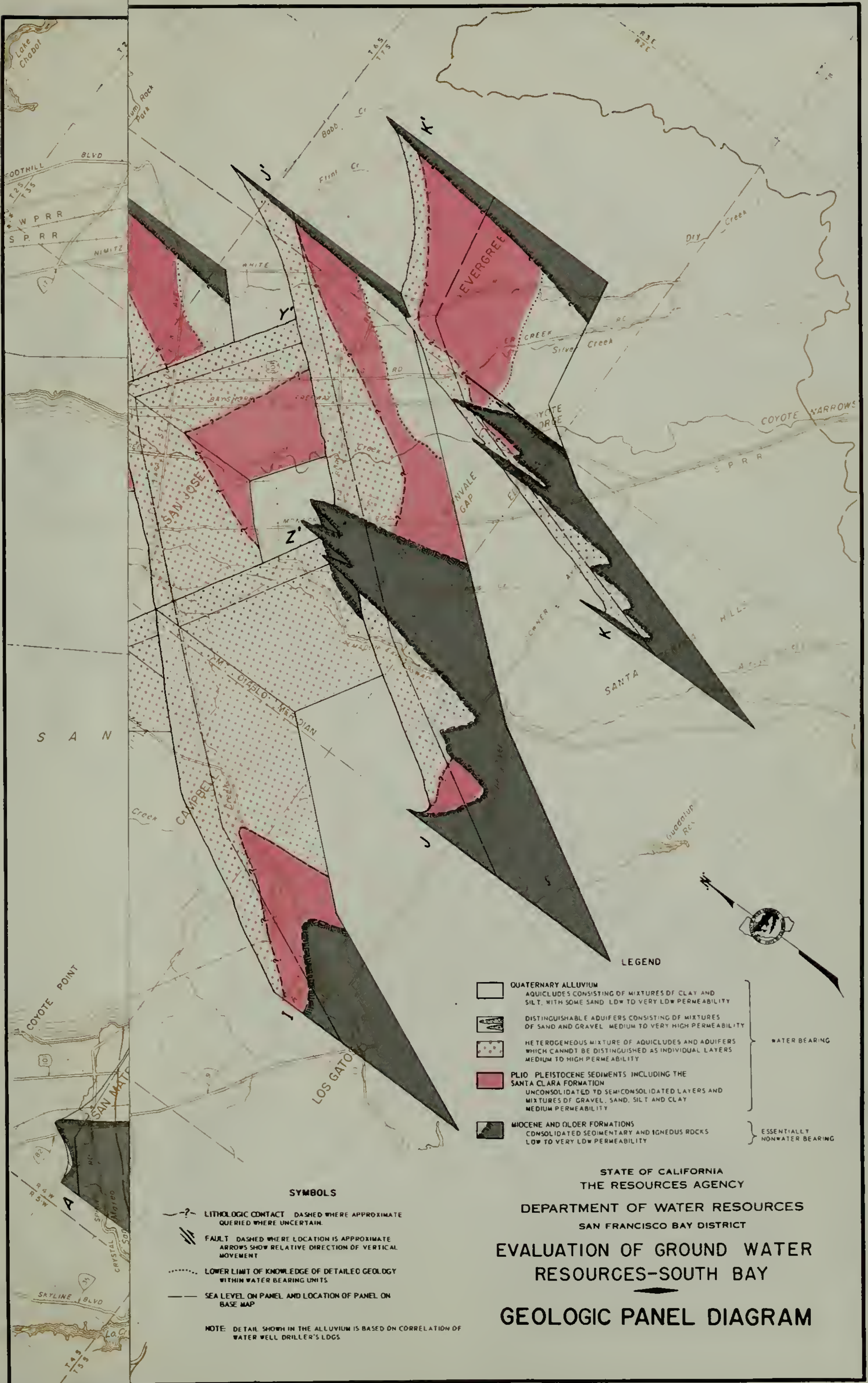
SOUTH BAY
APPROXIMATE DEPTH TO BASE OF WATER-BEARING SEDIMENTS
SHOWING WELL LOG CONTROL
SCALE OF MILES
0 1 2 3



Lake Chabot
FOOTHILL BLVD
W P R R
S P R R
NIMITZ
WHITE
Flint Cr
Dry Creek
EVERGREEN
Silver Creek
COYOTE NARROWS
S P R R
SAN JOSE
NYVALE GAP
Y'
Z'
J'
K'
K
J
I
A
SANTA TERESA HILLS
MT DIABLO MERIDIAN
S A N
CAMPBELL
Creek
LOS GATOS
COYOTE POINT
SAN MATEO
SKYLINE BLVD
Guadalupe Res
LEGEND
QUATERNARY ALLUVIUM
AQUICLUDES CONSISTING OF MIXTURES OF CLAY AND SILT, WITH SOME SAND LOW TO VERY LOW PERMEABILITY
DISTINGUISHABLE AQUIFERS CONSISTING OF MIXTURES OF SAND AND GRAVEL MEDIUM TO VERY HIGH PERMEABILITY
HETEROGENEOUS MIXTURE OF AQUICLUDES AND AQUIFERS WHICH CANNOT BE DISTINGUISHED AS INDIVIDUAL LAYERS MEDIUM TO HIGH PERMEABILITY
PLIO PLEISTOCENE SEDIMENTS, INCLUDING THE SANTA CLARA FORMATION
UNCONSOLIDATED TO SEMICONSOLIDATED LAYERS AND MIXTURES OF GRAVEL, SAND, SILT AND CLAY MEDIUM PERMEABILITY
WATER BEARING
MIOCENE AND OLDER FORMATIONS
CONSOLIDATED SEDIMENTARY AND IGNEOUS ROCKS, LOW TO VERY LOW PERMEABILITY
ESSENTIALLY NONWATER BEARING
SYMBOLS
LITHOLOGIC CONTACT DASHED WHERE APPROXIMATE QUERIED WHERE UNCERTAIN
FAULT DASHED WHERE LOCATION IS APPROXIMATE ARROWS SHOW RELATIVE DIRECTION OF VERTICAL MOVEMENT
LOWER LIMIT OF KNOWLEDGE OF DETAILED GEOLOGY WITHIN WATER BEARING UNITS
SEA LEVEL ON PANEL AND LOCATION OF PANEL ON BASE MAP
NOTE: DETAIL SHOWN IN THE ALLUVIUM IS BASED ON CORRELATION OF WATER WELL DRILLER'S LOGS
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER RESOURCES-SOUTH BAY
GEOLOGIC PANEL DIAGRAM



LEGEND

QUATERNARY ALLUVIUM

AQUICLUDES CONSISTING OF MIXTURES OF CLAY AND SILT, WITH SOME SAND LOW TO VERY LOW PERMEABILITY

DISTINGUISHABLE AQUIFERS CONSISTING OF MIXTURES OF SAND AND GRAVEL MEDIUM TO VERY HIGH PERMEABILITY

HETEROGENEOUS MIXTURE OF AQUICLUDES AND AQUIFERS WHICH CANNOT BE DISTINGUISHED AS INDIVIDUAL LAYERS MEDIUM TO HIGH PERMEABILITY

PLIO PLEISTOCENE SEDIMENTS INCLUDING THE SANTA CLARA FORMATION

UNCONSOLIDATED TO SEMICONSOLIDATED LAYERS AND MIXTURES OF GRAVEL, SAND, SILT AND CLAY MEDIUM PERMEABILITY

WATER BEARING

MIOCENE AND OLDER FORMATIONS

CONSOLIDATED SEDIMENTARY AND IGNEOUS ROCKS LOW TO VERY LOW PERMEABILITY

ESSENTIALLY NONWATER BEARING

SYMBOLS

LITHOLOGIC CONTACT DASHED WHERE APPROXIMATE QUERIED WHERE UNCERTAIN

FAULT DASHED WHERE LOCATION IS APPROXIMATE ARROWS SHOW RELATIVE DIRECTION OF VERTICAL MOVEMENT

LOWER LIMIT OF KNOWLEDGE OF DETAILED GEOLOGY WITHIN WATER BEARING UNITS

SEA LEVEL ON PANEL AND LOCATION OF PANEL ON BASE MAP

NOTE: DETAIL SHOWN IN THE ALLUVIUM IS BASED ON CORRELATION OF WATER WELL DRILLER'S LOGS

STATE OF CALIFORNIA
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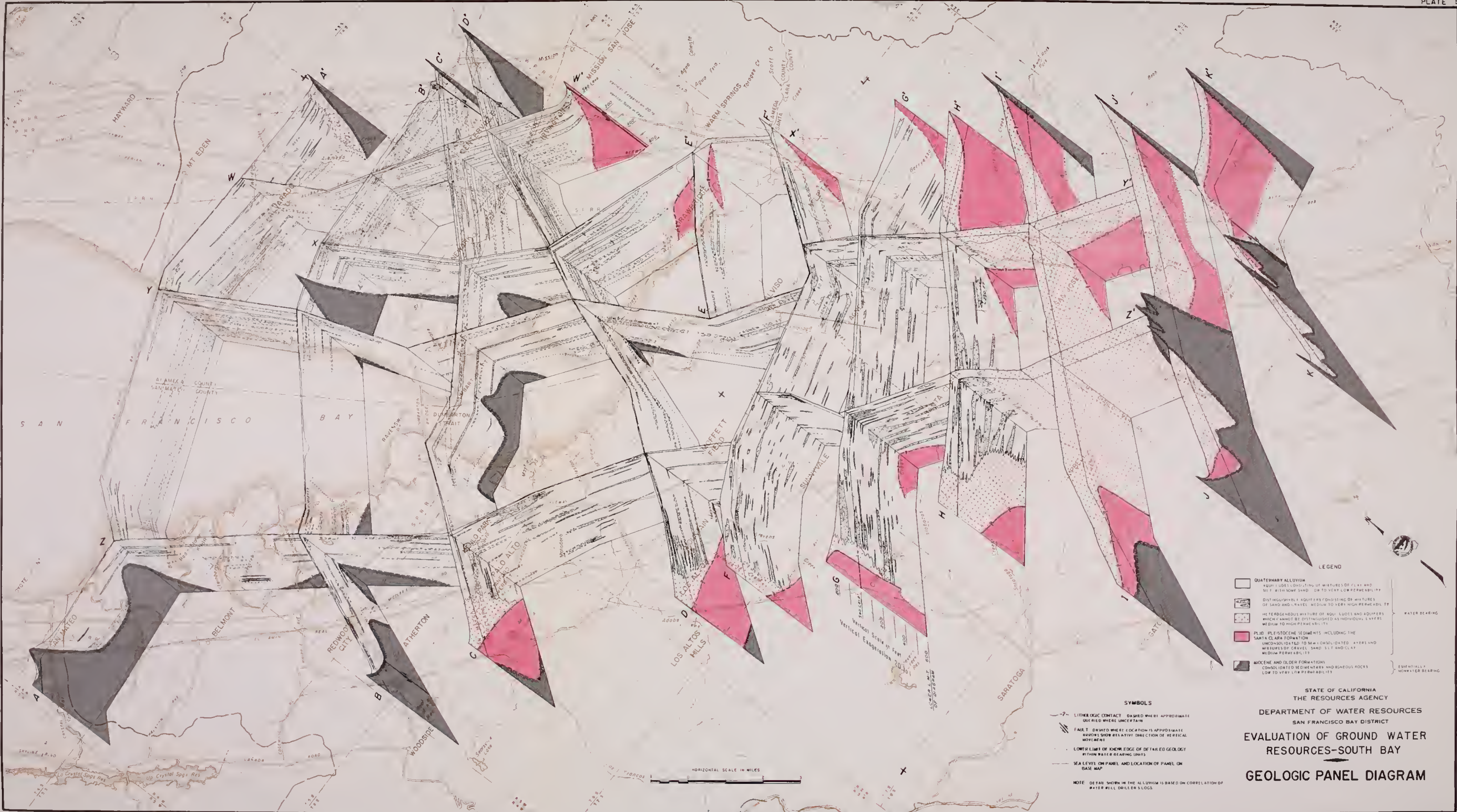
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES–SOUTH BAY

GEOLOGIC PANEL DIAGRAM


HAYWARD
MT EDEN
ALVARADO
CENTERVILLE
IRVINGTON
MISSION SAN JOSE
WARM SPRINGS
ALAMEDA COUNTY
SANTA CLARA COUNTY
ALAMEDA COUNTY
SAN MATEO COUNTY
SAN FRANCISCO BAY
DUMBARTON STRAIT
MOFFETT FIELD
SUNNYVALE
ALVISO
SAN JOSE
SANTA CLARA
MENLO PARK
PALO ALTO
LOS ALTOS
LOS ALTOS HILLS
SARATOGA
SAN MATEO
BELMONT
REDWOOD CITY
ATHERTON
WOODSIDE
Vertical Scale in Feet
Vertical Exaggeration 20:1
HORIZONTAL SCALE IN MILES
LEGEND
QUATERNARY ALLUVIUM
AQUICLUDES CONSISTING OF MIXTURES OF CLAY AND SILT WITH SOME SAND. LOW TO VERY LOW PERMEABILITY
DISTINGUISHABLE AQUIFERS CONSISTING OF MIXTURES OF SAND AND GRAVEL. MEDIUM TO VERY HIGH PERMEABILITY
HETEROGENEOUS MIXTURE OF AQUICLUDES AND AQUIFERS WHICH CANNOT BE DISTINGUISHED AS INDIVIDUAL LAYERS. MEDIUM TO HIGH PERMEABILITY
PLIO-PLEISTOCENE SEDIMENTS INCLUDING THE SANTA CLARA FORMATION
UNCONSOLIDATED TO SEMI-CONSOLIDATED LAYERS AND MIXTURES OF GRAVEL, SAND, SILT AND CLAY. MEDIUM PERMEABILITY
WATER BEARING
MIOCENE AND OLDER FORMATIONS
CONSOLIDATED SEDIMENTARY AND IGNEOUS ROCKS. LOW TO VERY LOW PERMEABILITY
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SYMBOLS
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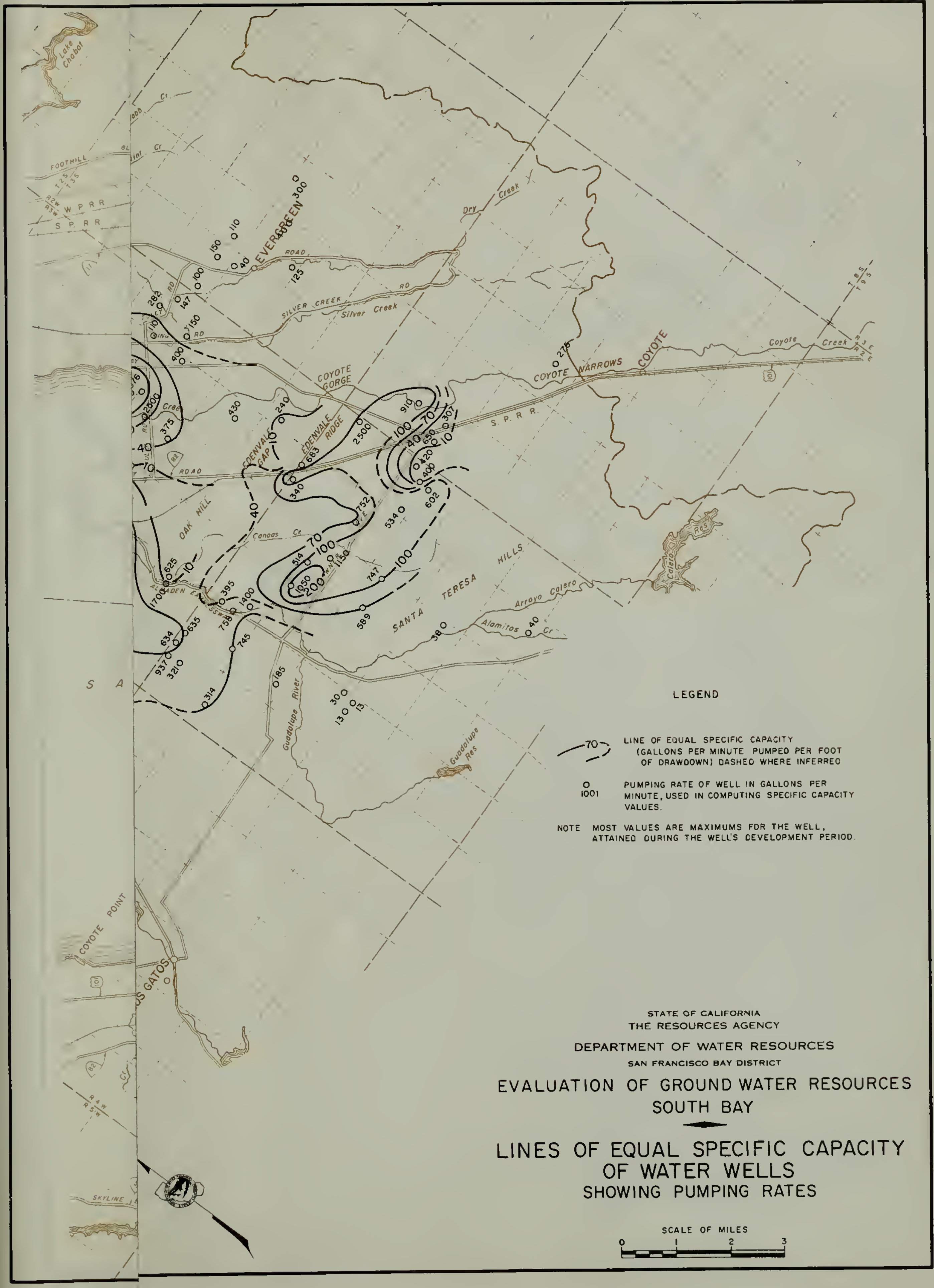
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER RESOURCES–SOUTH BAY
GEOLOGIC PANEL DIAGRAM



STATE OF CALIFORNIA
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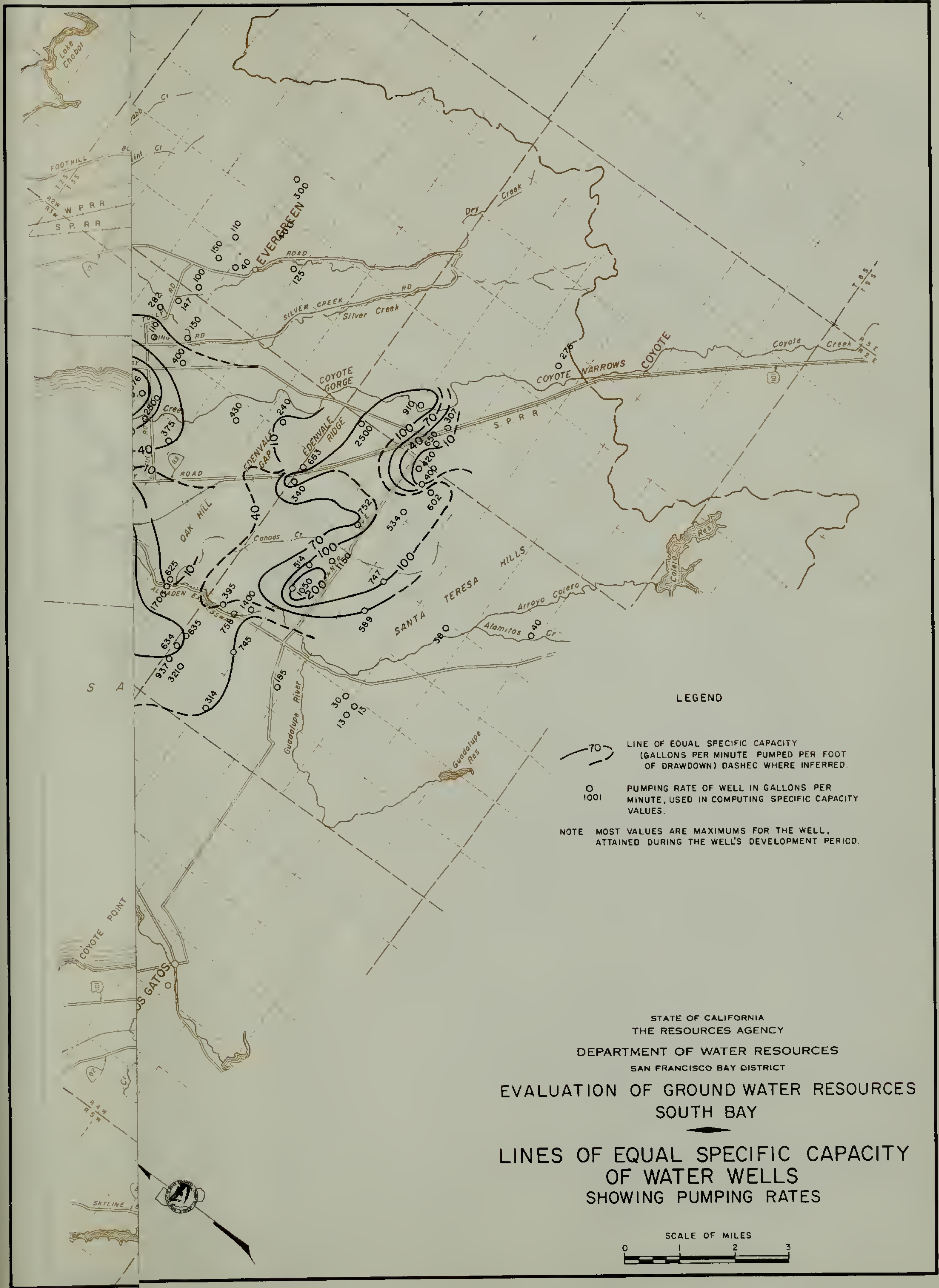
EVALUATION OF GROUND WATER RESOURCES
SOUTH BAY

LINES OF EQUAL SPECIFIC CAPACITY OF WATER WELLS
SHOWING PUMPING RATES



LEGEND

LINE OF EQUAL SPECIFIC CAPACITY (GALLONS PER MINUTE PUMPED PER FOOT OF DRAWDOWN) DASHED WHERE INFERRED.

1001 — PUMPING RATE OF WELL IN GALLONS PER MINUTE, USED IN COMPUTING SPECIFIC CAPACITY VALUES.

NOTE: MOST VALUES ARE MAXIMUMS FOR THE WELL, ATTAINED DURING THE WELL'S DEVELOPMENT PERIOD.

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EVALUATION OF GROUND WATER RESOURCES
SOUTH BAY

LINES OF EQUAL SPECIFIC CAPACITY OF WATER WELLS
SHOWING PUMPING RATES

SCALE OF MILES
0 1 2 3


HAYWARD
MT. EDEN
ALVARADO
NEWARK
IRVINGTON
MISSION SAN JOSE
WARM SPRINGS
DRAWBRIDGE
MILPITAS
ALVISO
AGNEW
SAN JOSE
EVERGREEN
COYOTE
COYOTE NARROWS
SANTA TERESA HILLS
MOFFETT FIELD
MOUNTAIN VIEW
SUNNYVALE
LOS ALTOS
LOS ALTOS HILLS
PALO ALTO
ATHERTON
REDWOOD CITY
BELMONT
SAN MATEO
WOODSIDE
SARATOGA
LOS GATOS
CUPERTINO
CAMPBELL
SAN FRANCISCO BAY
DUMBARTON STRAIT
DUMBARTON PT.
ALAMEDA CO.
SANTA CLARA CO.
SAN MATEO CO.
LEGEND
LINE OF EQUAL SPECIFIC CAPACITY (GALLONS PER MINUTE PUMPED PER FOOT OF DRAWDOWN) DASHED WHERE INFERRED
PUMPING RATE OF WELL IN GALLONS PER MINUTE, USED IN COMPUTING SPECIFIC CAPACITY VALUES
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STATE OF CALIFORNIA
THE RESOURCES AGENCY
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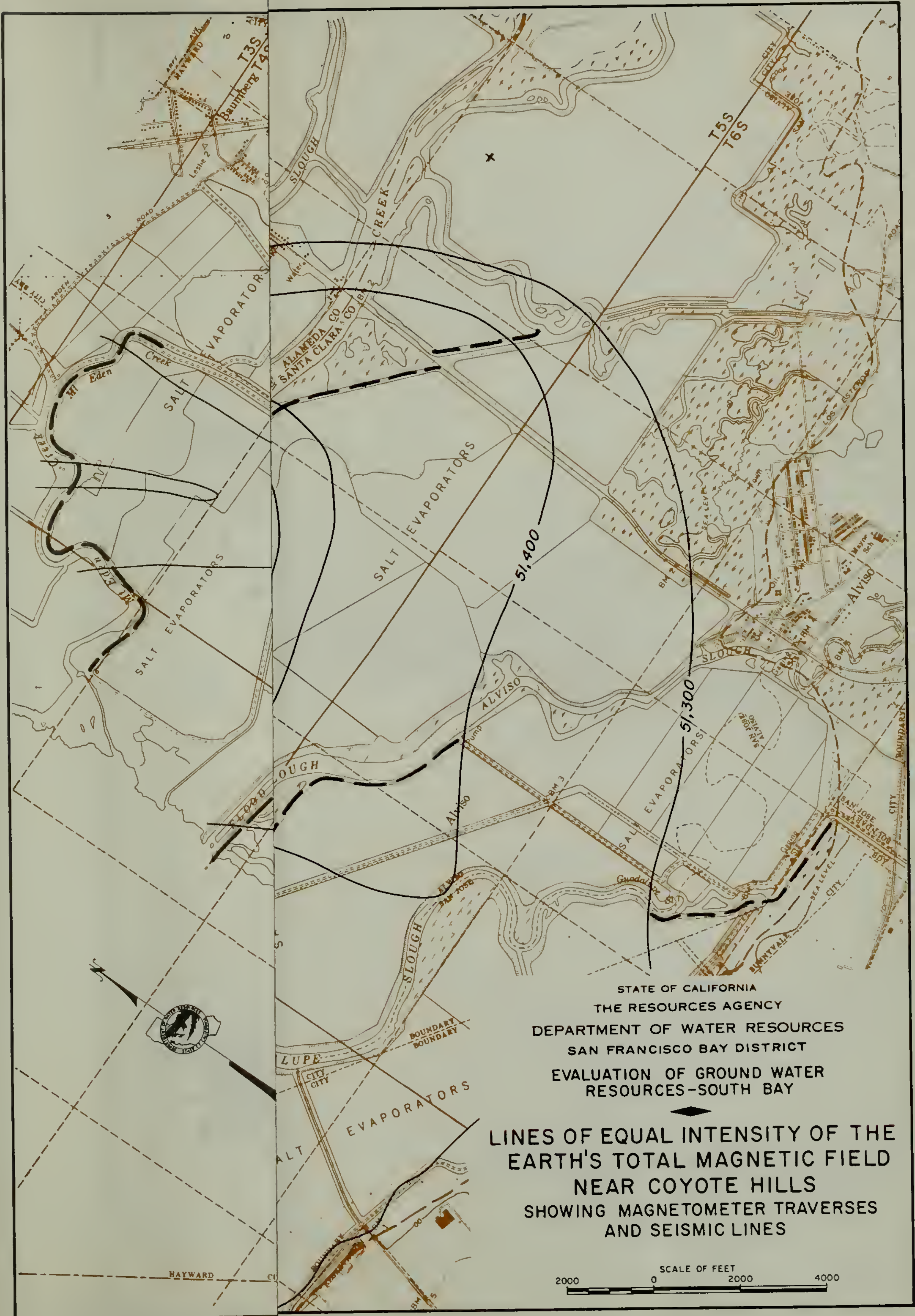
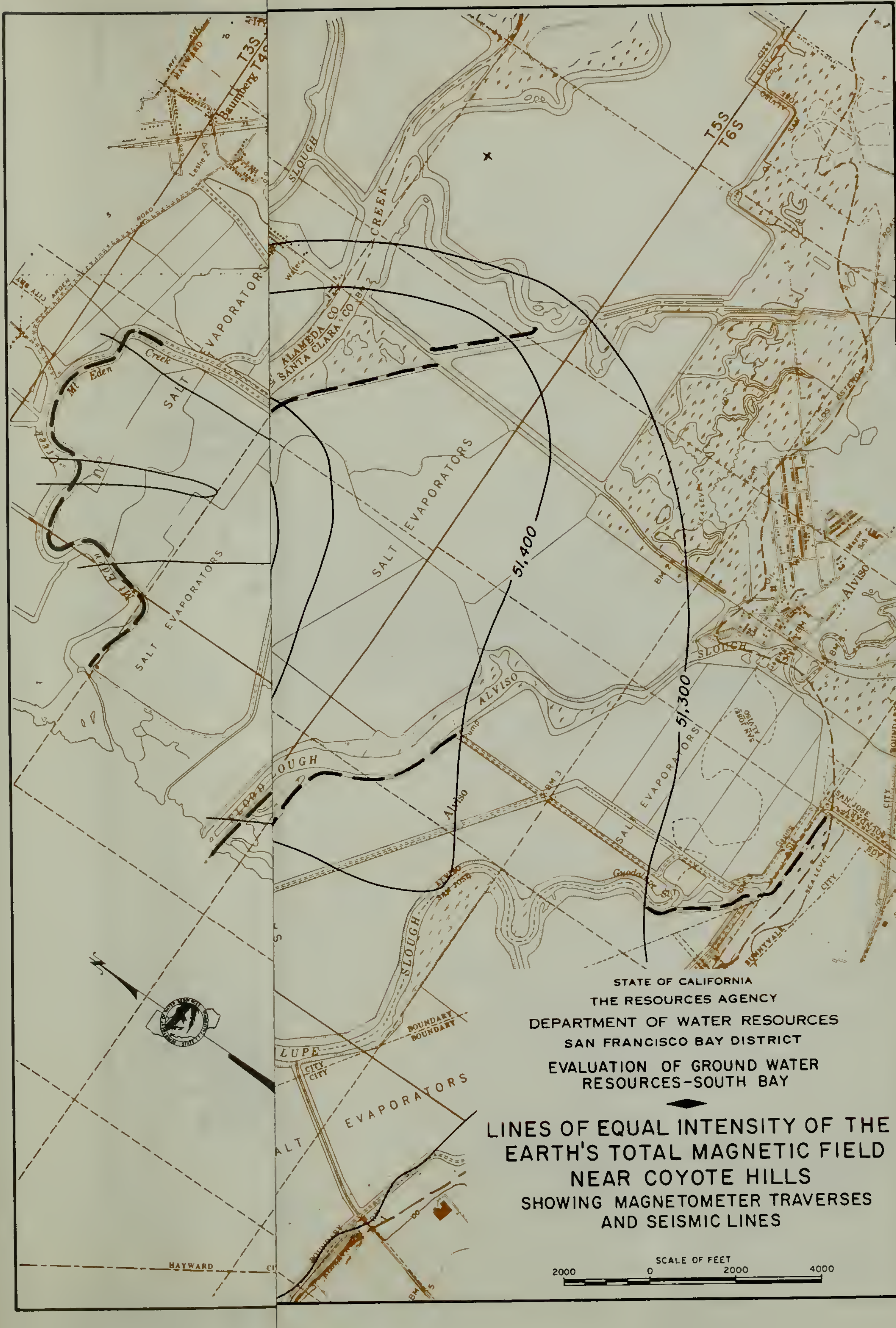
SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER RESOURCES
SOUTH BAY
LINES OF EQUAL SPECIFIC CAPACITY
OF WATER WELLS
SHOWING PUMPING RATES
SCALE OF MILES
0
1
2
3


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER RESOURCES-SOUTH BAY
LINES OF EQUAL INTENSITY OF THE EARTH'S TOTAL MAGNETIC FIELD NEAR COYOTE HILLS
SHOWING MAGNETOMETER TRAVERSES AND SEISMIC LINES
SCALE OF FEET
2000
0
2000
4000
51,400
51,300
T3S
T4S
T5S
T6S
SALT EVAPORATORS
ALAMEDA CO
SANTA CLARA CO
CREEK
SLOUGH
ALVISO
Alviso
Mt Eden Creek
GUADALUPE
HAYWARD
BOUNDARY
CITY
Baumberg
Leslie
SAN JOSE
LOS ESTEROS
BM 2
BM 3
SEA LEVEL
SUNNYVALE



STATE OF CALIFORNIA
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DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES-SOUTH BAY

LINES OF EQUAL INTENSITY OF THE EARTH'S TOTAL MAGNETIC FIELD NEAR COYOTE HILLS

SHOWING MAGNETOMETER TRAVERSES AND SEISMIC LINES

SCALE OF FEET

STATE OF CALIFORNIA
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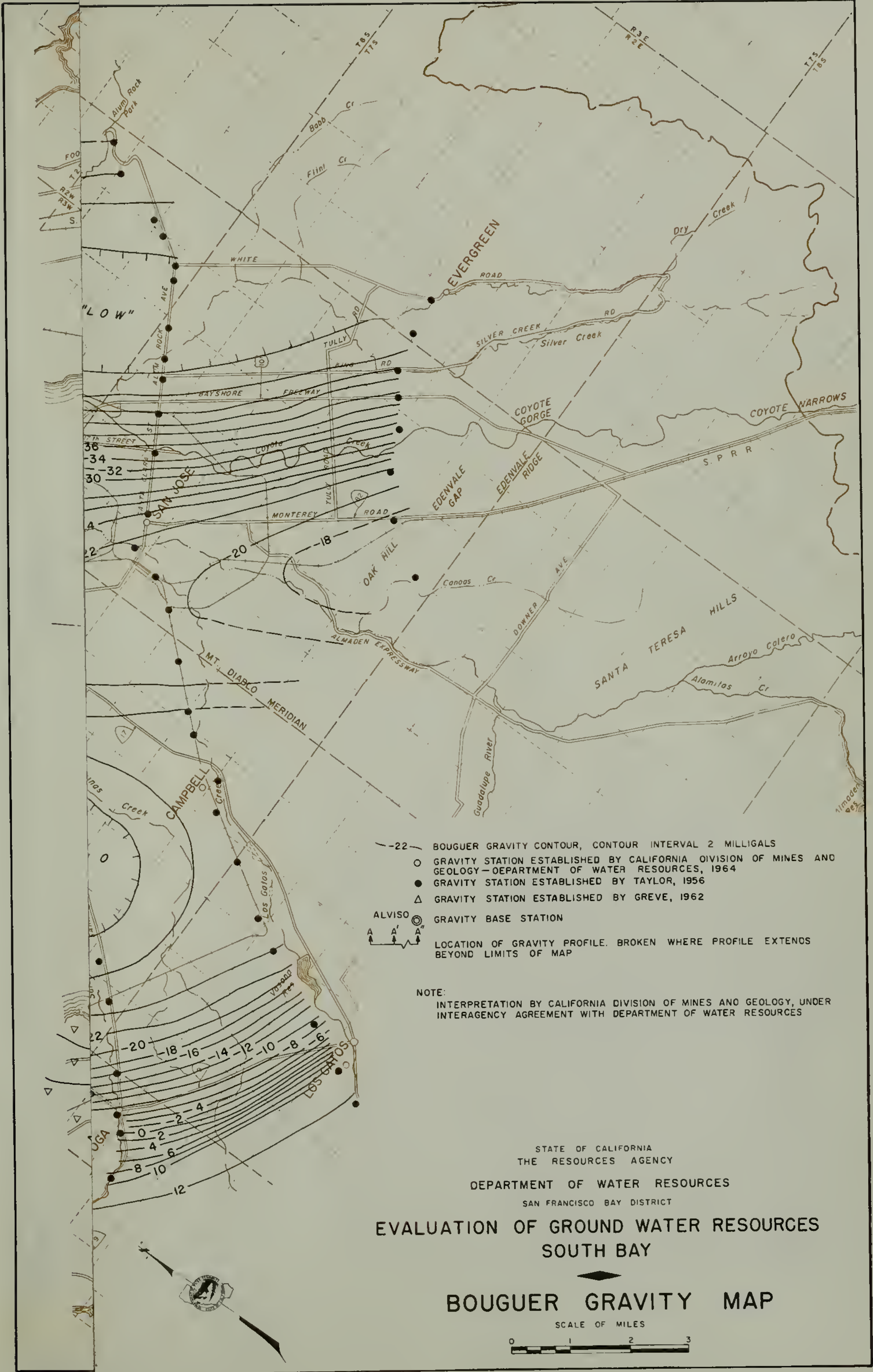
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES-SOUTH BAY

LINES OF EQUAL INTENSITY OF THE EARTH'S TOTAL MAGNETIC FIELD NEAR COYOTE HILLS
SHOWING MAGNETOMETER TRAVERSES AND SEISMIC LINES



—22— BOUGUER GRAVITY CONTOUR, CONTOUR INTERVAL 2 MILLIGALS

○ GRAVITY STATION ESTABLISHED BY CALIFORNIA DIVISION OF MINES AND GEOLOGY—DEPARTMENT OF WATER RESOURCES, 1964

● GRAVITY STATION ESTABLISHED BY TAYLOR, 1956

△ GRAVITY STATION ESTABLISHED BY GREVE, 1962

ALVISO ◎ GRAVITY BASE STATION

A A' A'' LOCATION OF GRAVITY PROFILE. BROKEN WHERE PROFILE EXTENDS BEYOND LIMITS OF MAP

NOTE:
INTERPRETATION BY CALIFORNIA DIVISION OF MINES AND GEOLOGY, UNDER INTERAGENCY AGREEMENT WITH DEPARTMENT OF WATER RESOURCES

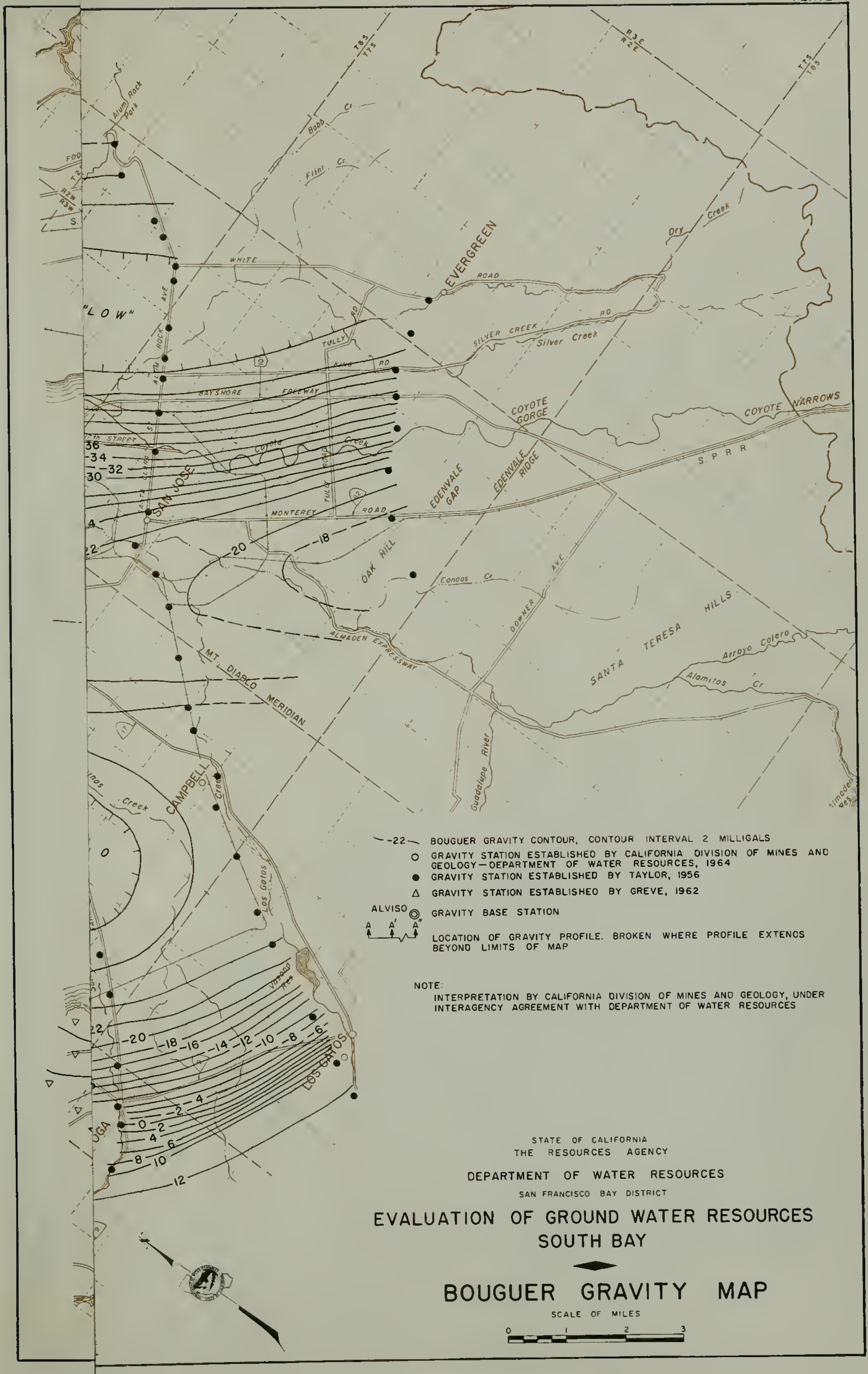
STATE OF CALIFORNIA
THE RESOURCES AGENCY

DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES
SOUTH BAY

BOUGUER GRAVITY MAP

SCALE OF MILES
0 1 2 3



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ALVISO ◎ GRAVITY BASE STATION

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STATE OF CALIFORNIA
THE RESOURCES AGENCY

DEPARTMENT OF WATER RESOURCES

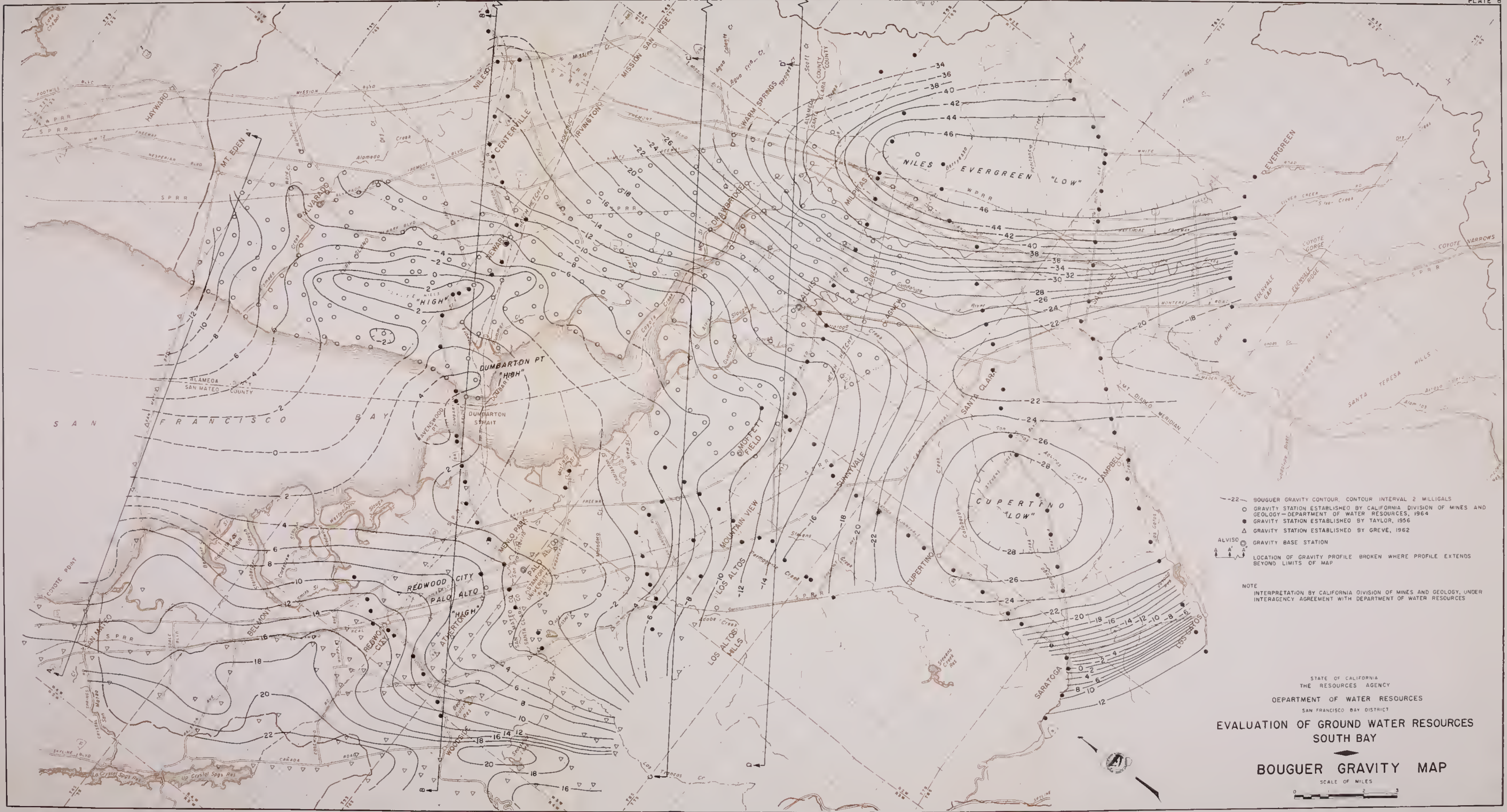
SAN FRANCISCO BAY DISTRICT

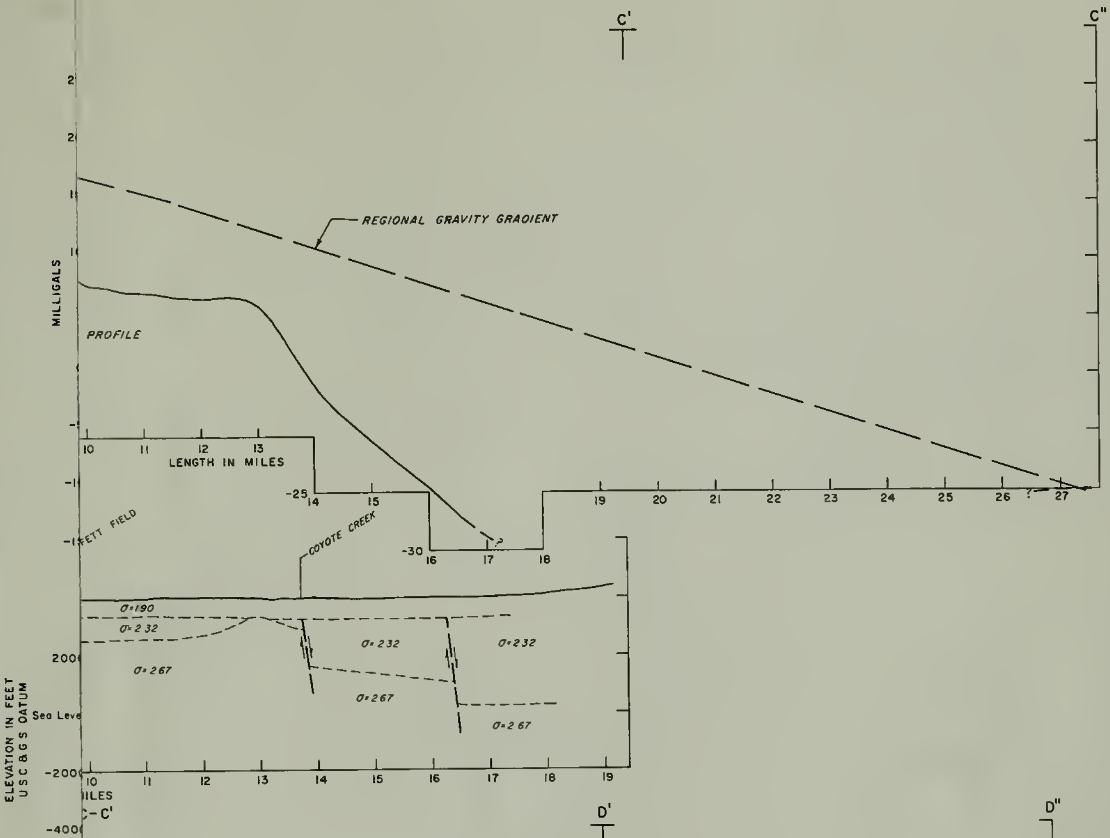
EVALUATION OF GROUND WATER RESOURCES
SOUTH BAY

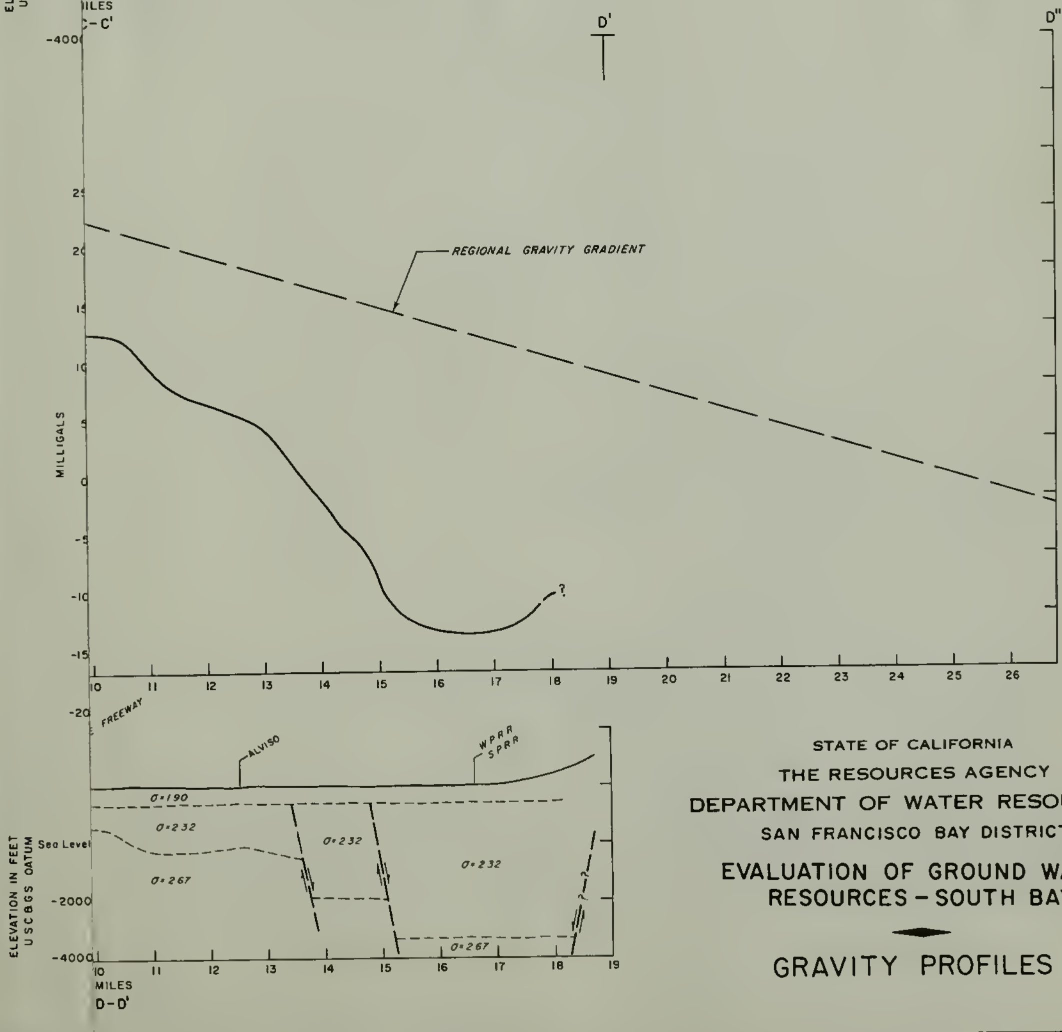
BOUGUER GRAVITY MAP

SCALE OF MILES

0 1 2 3


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER RESOURCES
SOUTH BAY
BOUGUER GRAVITY MAP
SCALE OF MILES
0 1 2 3
-22 BOUGUER GRAVITY CONTOUR, CONTOUR INTERVAL 2 MILLIGALS
GRAVITY STATION ESTABLISHED BY CALIFORNIA DIVISION OF MINES AND GEOLOGY—DEPARTMENT OF WATER RESOURCES, 1964
GRAVITY STATION ESTABLISHED BY TAYLOR, 1956
GRAVITY STATION ESTABLISHED BY GREVE, 1962
ALVISO
GRAVITY BASE STATION
A A' A"
LOCATION OF GRAVITY PROFILE BROKEN WHERE PROFILE EXTENDS BEYOND LIMITS OF MAP
NOTE
INTERPRETATION BY CALIFORNIA DIVISION OF MINES AND GEOLOGY, UNDER INTERAGENCY AGREEMENT WITH DEPARTMENT OF WATER RESOURCES
NILES EVERGREEN "LOW"
CUPERTINO "LOW"
DUMBARTON PT "HIGH"
REDWOOD CITY PALO ALTO "HIGH"
"HIGH"
DUMBARTON STRAIT
SAN FRANCISCO BAY
HAYWARD
MT. EDEN
ALVARADO
NILES
CENTERVILLE
IRVINGTON
MISSION SAN JOSE
WARM SPRINGS
DRAWBRIDGE
MILPITAS
EVERGREEN
ALVISO
AGNEW
SAN JOSE
SANTA CLARA
CAMPBELL
LOS GATOS
SARATOGA
CUPERTINO
SUNNYVALE
MOFFETT FIELD
MOUNTAIN VIEW
LOS ALTOS
LOS ALTOS HILLS
PALO ALTO
MENLO PARK
ATHERTON
REDWOOD CITY
WOODSIDE
BELMONT
SAN MATEO
COYOTE POINT
RAVENSWOOD PT
ALAMEDA COUNTY
SAN MATEO COUNTY
COYOTE NARROWS
COYOTE GORGE
EDENVALE GAP
EDENVALE RIDGE
OAK HILL
SANTA TERESA HILLS
MT DIABLO MERIDIAN
SPRR
WPRR





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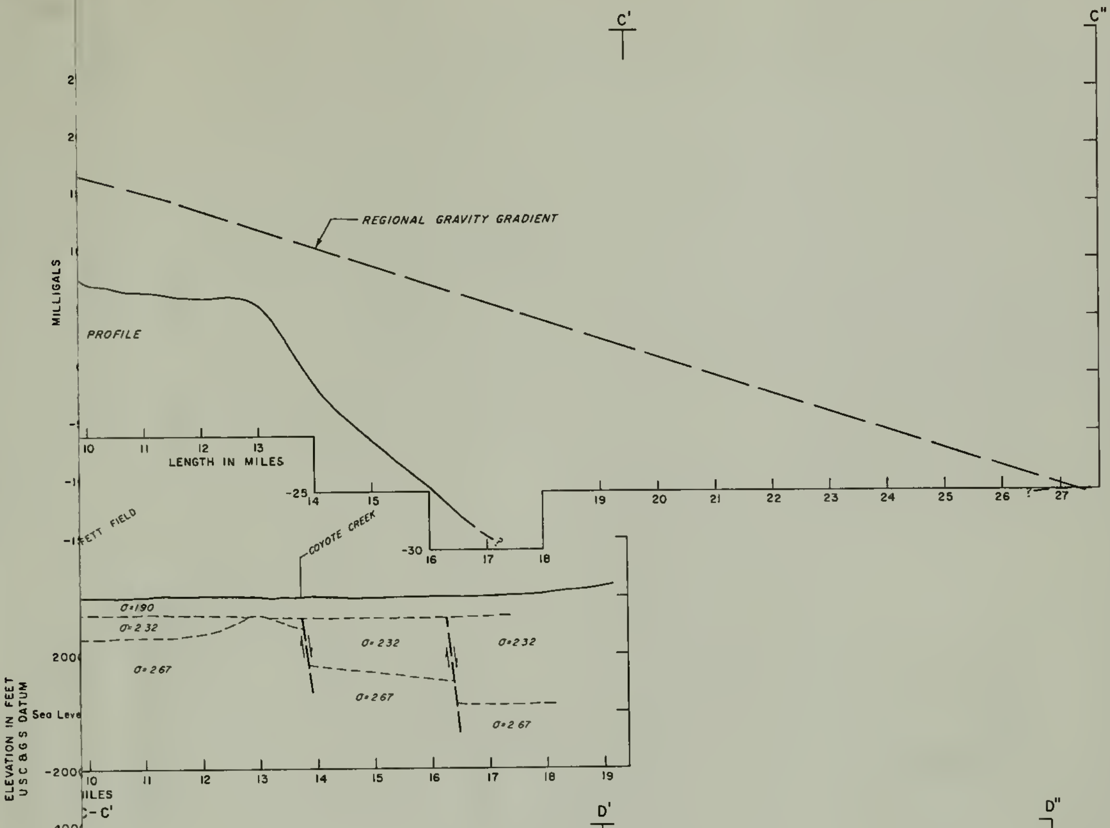
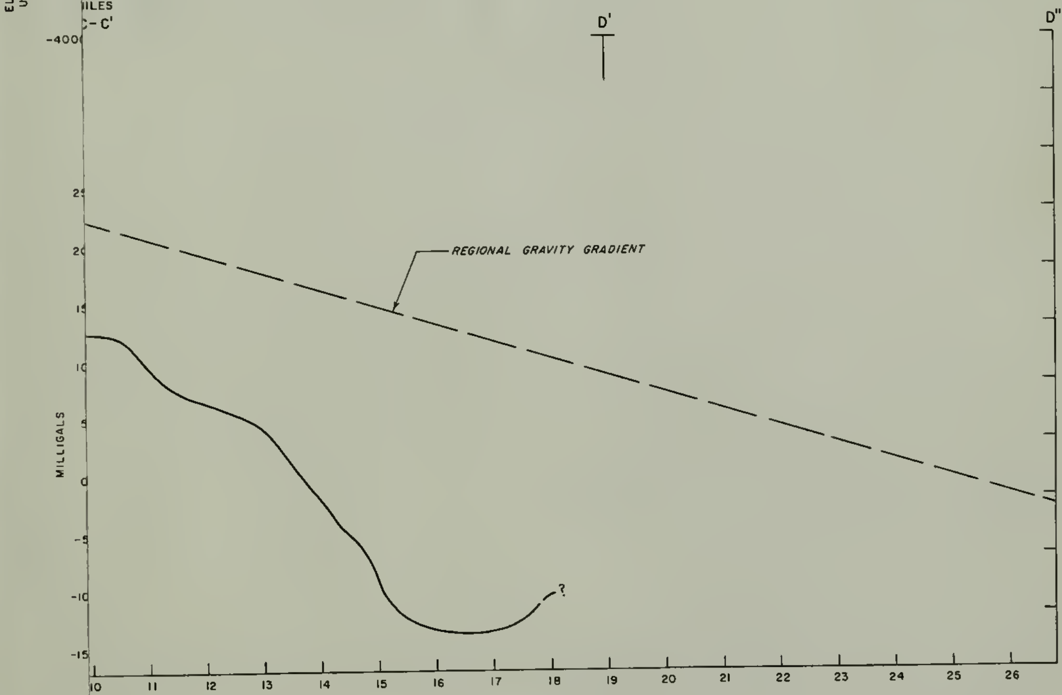
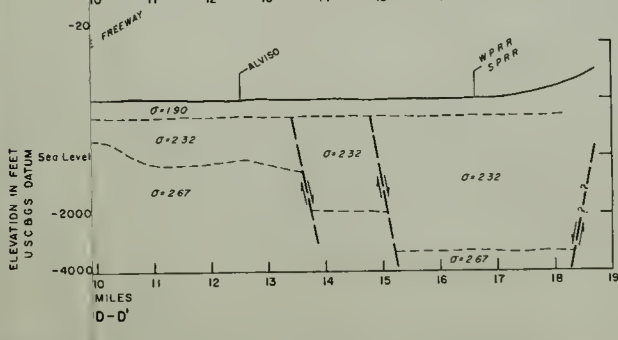
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES - SOUTH BAY

GRAVITY PROFILES







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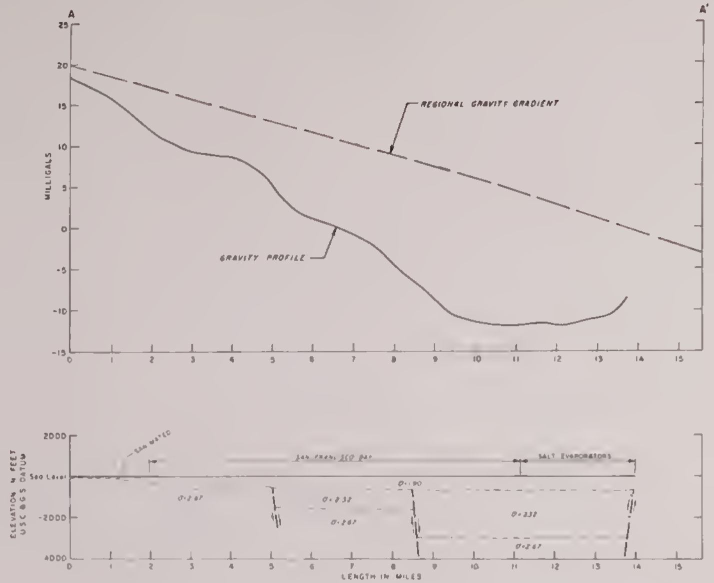
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES - SOUTH BAY

GRAVITY PROFILES



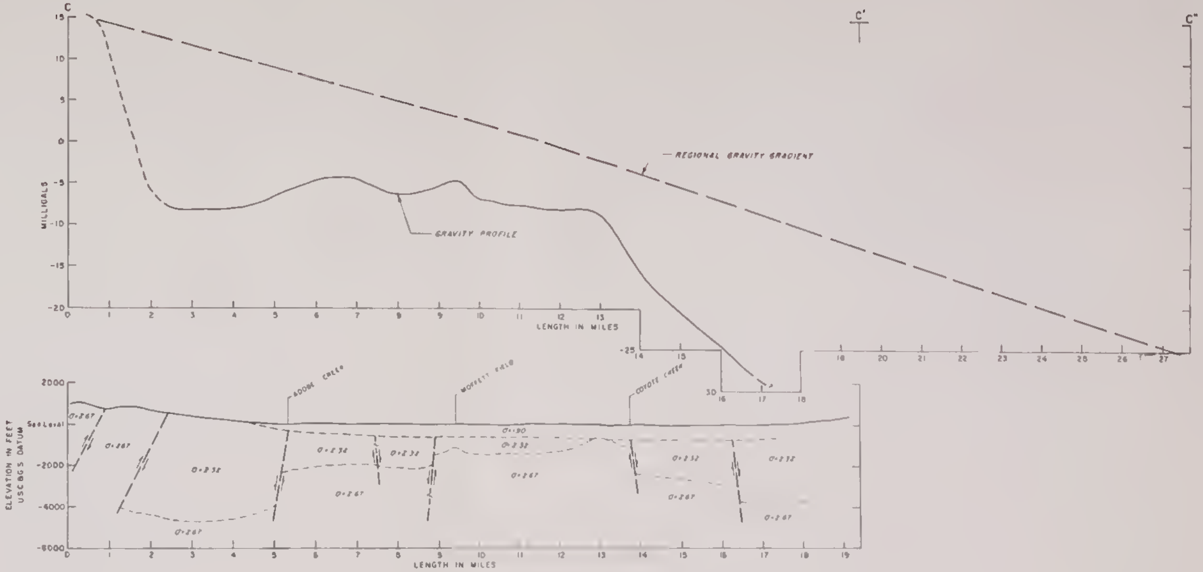
PROFILE A-A'

EXPLANATION OF DENSITY UNITS

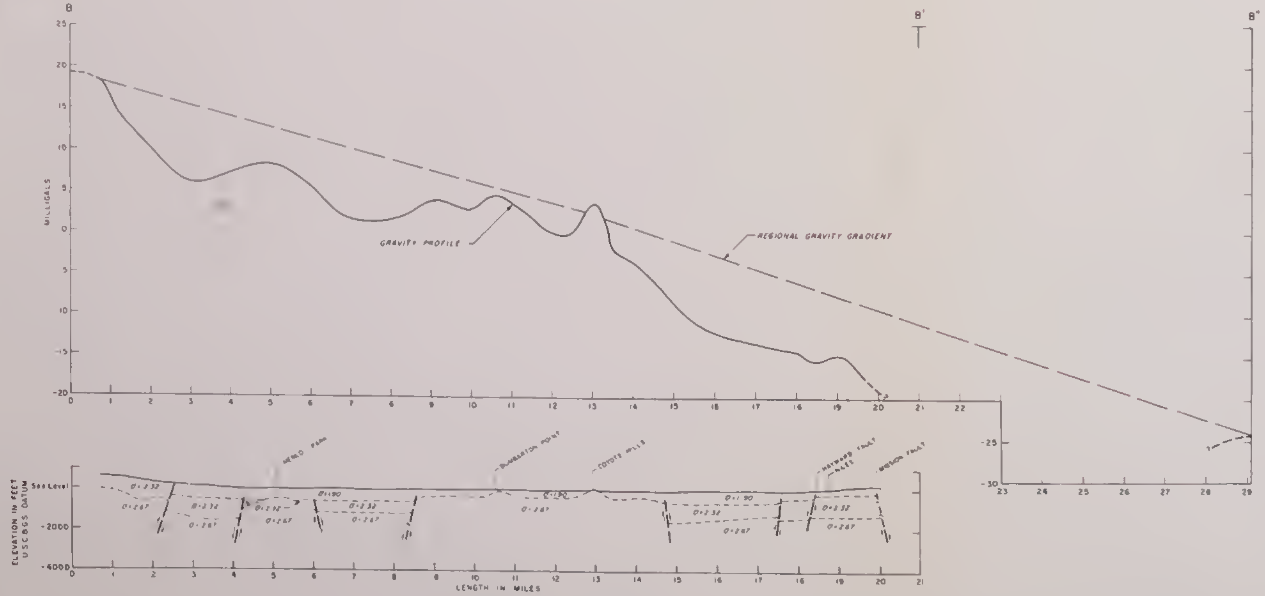
σ·1.90 = UPPER PLEISTOCENE AND RECENT ALLUVIUM, COMPOSED OF GRAVEL, SAND, SILT AND CLAY

σ·2.32 = PLIO-PLEISTOCENE, TERTIARY, AND POSSIBLY CRETACEOUS SEDIMENTS

σ·2.67 = FRANCISCAN FORMATION



PROFILE C-C'



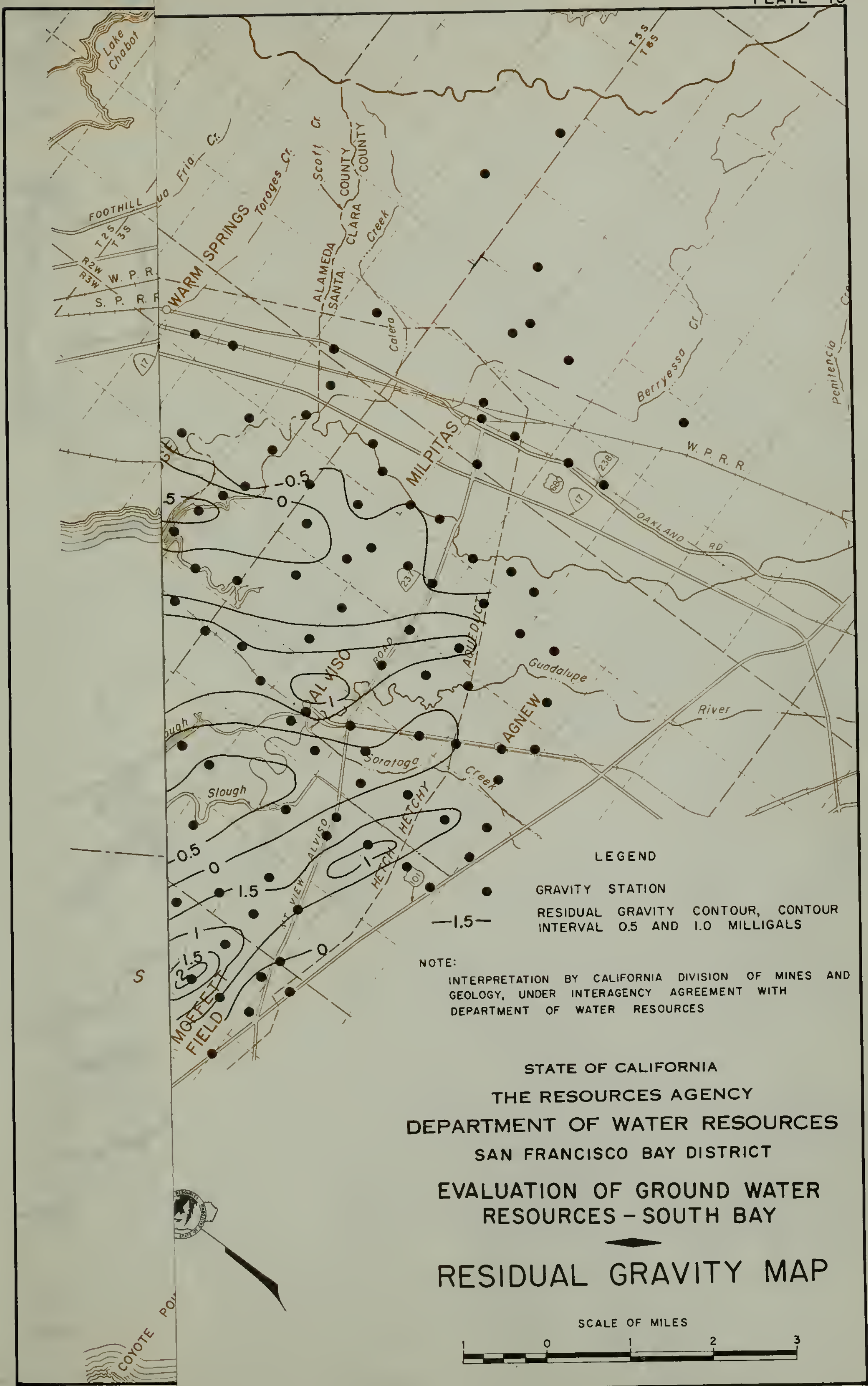
PROFILE B-B'

PROFILE D-D'

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES – SOUTH BAY

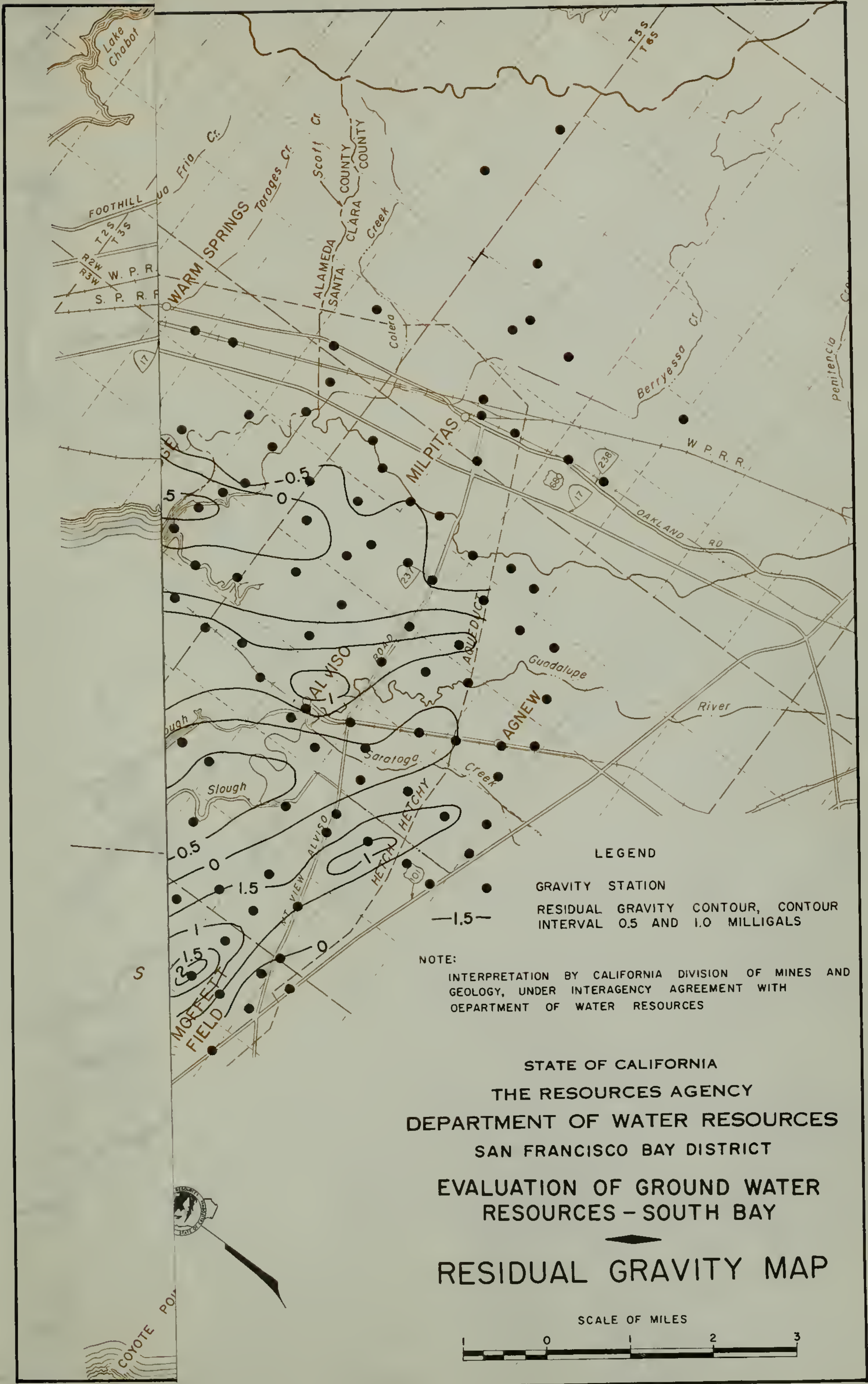
GRAVITY PROFILES



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES – SOUTH BAY

RESIDUAL GRAVITY MAP


Lake Chabot
FOOTHILL
Agua Fria Cr.
Toroges Cr.
Scott Cr.
ALAMEDA COUNTY
SANTA CLARA COUNTY
Creek
T2S
T3S
T5S
T6S
R2W
R3W
W. P. R. R.
S. P. R. R.
WARM SPRINGS
Calera
Berryessa Cr.
Penitencia
MILPITAS
W. P. R. R.
OAKLAND RD
ALVISO
ROAD
AQUEDUCT
Guadalupe
River
AGNEW
Saratoga
Creek
Slough
Slough
HETCH HETCHY
MT. VIEW ALVISO
MOFFETT FIELD
COYOTE POINT
-0.5
0
0.5
-1
1.5
2
LEGEND
GRAVITY STATION
—1.5— RESIDUAL GRAVITY CONTOUR, CONTOUR INTERVAL 0.5 AND 1.0 MILLIGALS
NOTE:
INTERPRETATION BY CALIFORNIA DIVISION OF MINES AND GEOLOGY, UNDER INTERAGENCY AGREEMENT WITH DEPARTMENT OF WATER RESOURCES
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER RESOURCES - SOUTH BAY
RESIDUAL GRAVITY MAP
SCALE OF MILES
1 0 1 2 3


LEGEND
GRAVITY STATION
—1.5— RESIDUAL GRAVITY CONTOUR, CONTOUR INTERVAL 0.5 AND 1.0 MILLIGALS
NOTE:
INTERPRETATION BY CALIFORNIA DIVISION OF MINES AND GEOLOGY, UNDER INTERAGENCY AGREEMENT WITH DEPARTMENT OF WATER RESOURCES
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER RESOURCES – SOUTH BAY
RESIDUAL GRAVITY MAP
SCALE OF MILES
1 0 1 2 3
SAN FRANCISCO BAY
HAYWARD
MT. EDEN
ALVARADO
NILES
CENTERVILLE
NEWARK
IRVINGTON
MISSION SAN JOSE
WARM SPRINGS
MILPITAS
ALVISO
AGNEW
DRAWBRIDGE
MOFFETT FIELD
RAVENSWOOD PT.
DUMBARTON STRAIT
DUMBARTON PT.
MENLO PARK
PALO ALTO
STANFORD UNIVERSITY
COYOTE POINT
Lake Chabot
ALAMEDA COUNTY
SAN MATEO COUNTY
ALAMEDA COUNTY
SANTA CLARA COUNTY
HETCH HETCHY
AQUEDUCT
COYOTE HILLS
FOOTHILL BLVD
MISSION BLVD
NIMITZ FREEWAY
HESPERIAN BLVD
FREMONT BLVD
ALVARADO BLVD
NEWARK BLVD
BAYSHORE FREEWAY
S P R R
W P R R
Alameda Creek
Guadalupe River
Coyote Creek
Saratoga Creek
Berryessa Cr
Penitencia Cr
Mud Sl
Mowry Sl
Plummer Cr
Agua Caliente Cr
Agua Fria Cr
Toroges Cr
Scott Cr
Calera Cr
Dry Cr
Ward Cr
San Francisquito Cr
Matadero Cr
Charleston Sl
Mt. View Sl
Mayfield Sl
Westpoint Slough
Redwood Cr
Corkscrew Slough
Steinberger Slough
Belmont Sl
Bay Sl
Smith Sl
Radio Station KNBR
T 3 S
T 4 S
T 5 S
T 6 S
R 1 W
R 2 W
R 3 W
R 4 W

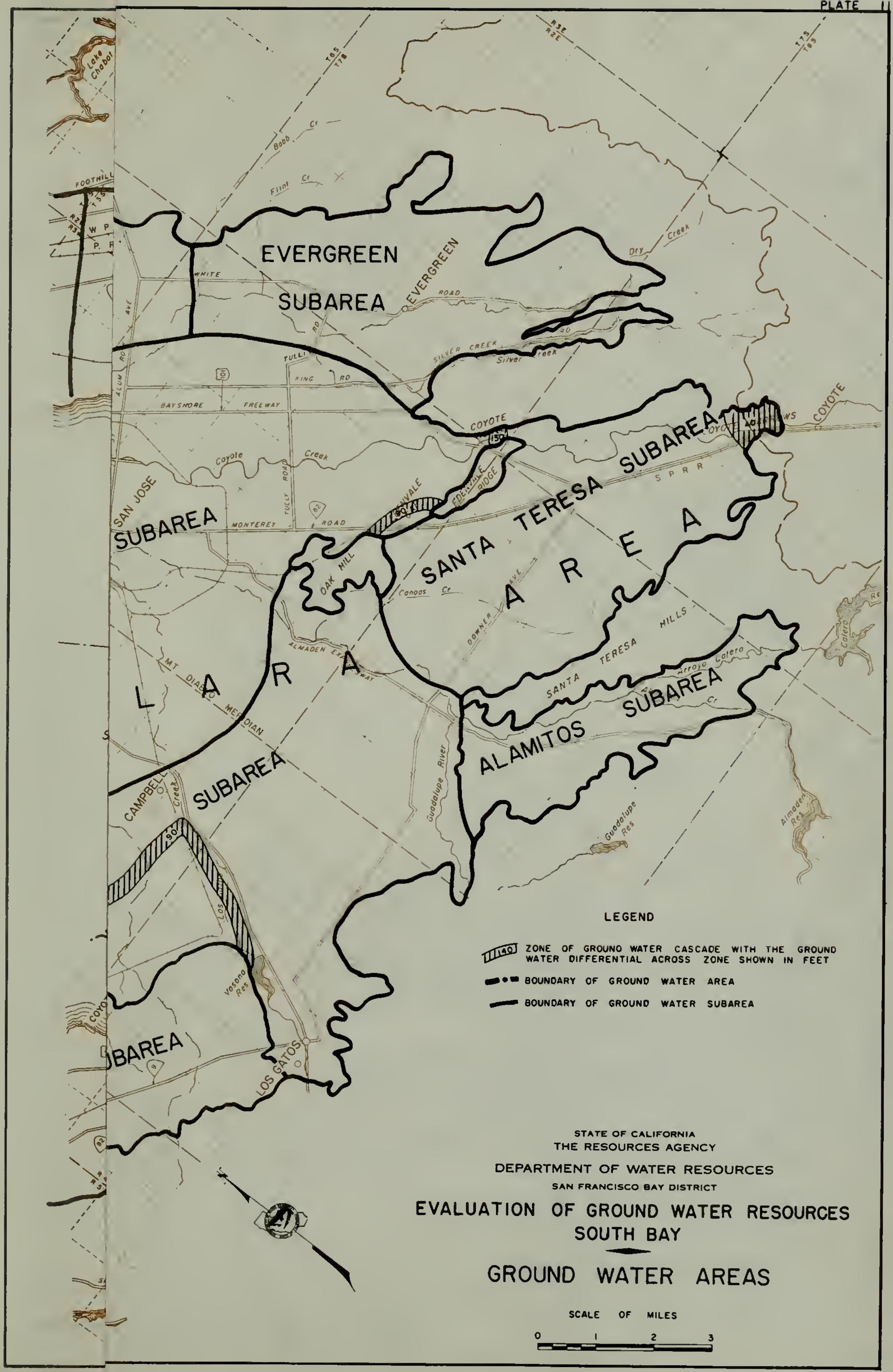
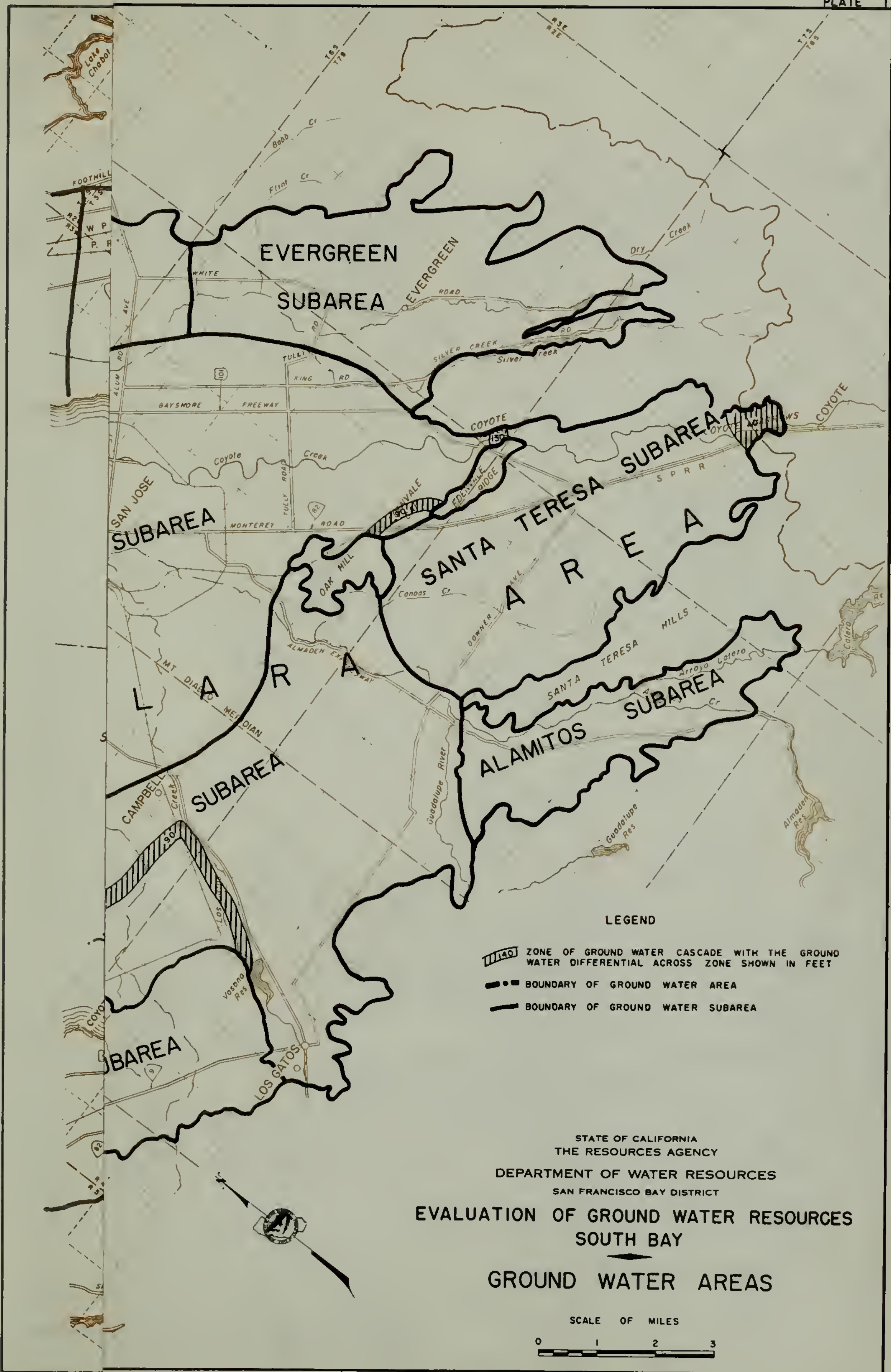


PLATE 11
EVERGREEN SUBAREA
SANTA TERESA SUBAREA
SANTA TERESA AREA
ALAMITOS SUBAREA
SAN JOSE SUBAREA
SANTA CLARA SUBAREA
BAREA
EVERGREEN
COYOTE
OAK HILL
SANTA TERESA HILLS
LOS GATOS
CAMPBELL
Lake Chabot
Flint Cr
Dry Creek
Silver Creek
SILVER CREEK RD
TULLY RD
KING RD
BAYSHORE FREEWAY
Coyote Creek
MONTEREY ROAD
Canoas Cr
ALMADEN EXPWY
MT DIABLO MERIDIAN
Guadalupe River
Guadalupe Res
Almaden Res
Calero Res
Arroyo Calero
Vasona Res
Los Gatos Creek
SPRR
LEGEND
140 ZONE OF GROUND WATER CASCADE WITH THE GROUND WATER DIFFERENTIAL ACROSS ZONE SHOWN IN FEET
BOUNDARY OF GROUND WATER AREA
BOUNDARY OF GROUND WATER SUBAREA
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER RESOURCES
SOUTH BAY
GROUND WATER AREAS
SCALE OF MILES
0 1 2 3



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES
SOUTH BAY

GROUND WATER AREAS


DRY CREEK SUBAREA
SAN LEANDRO CONE
FREMONT AREA
NILES SUBAREA
DEPOSITIONAL SHADOW
MISSION SUBAREA
WARM SPRINGS SUBAREA
BERRYESSA SUBAREA
EVERGREEN SUBAREA
SAN JOSE SUBAREA
SANTA TERESA SUBAREA
AREA
ALAMITOS SUBAREA
SANTA CLARA
WEST SIDE SUBAREA
SARATOGA SUBAREA
SAN FRANCISQUITO SUBAREA
BELMONT SUBAREA
SAN MATEO AREA
SAN FRANCISCO BAY
ALAMEDA COUNTY
SAN MATEO COUNTY
DUMBARTON STRAIT
MOFFETT FIELD
HAYWARD
NILES
CENTERVILLE
IRVINGTON
MT EDEN
ALVARADO
NEWARK
MILPITAS
ALVISO
AGNEW
SUNNYVALE
MOUNTAIN VIEW
LOS ALTOS
LOS ALTOS HILLS
CUPERTINO
CAMPBELL
LOS GATOS
SARATOGA
PALO ALTO
MENLO PARK
ATHERTON
REDWOOD CITY
WOODSIDE
SAN MATEO
COYOTE
LEGEND
ZONE OF GROUND WATER CASCADE WITH THE GROUND WATER DIFFERENTIAL ACROSS ZONE SHOWN IN FEET
BOUNDARY OF GROUND WATER AREA
BOUNDARY OF GROUND WATER SUBAREA
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER RESOURCES
SOUTH BAY
GROUND WATER AREAS
SCALE OF MILES
0 1 2 3

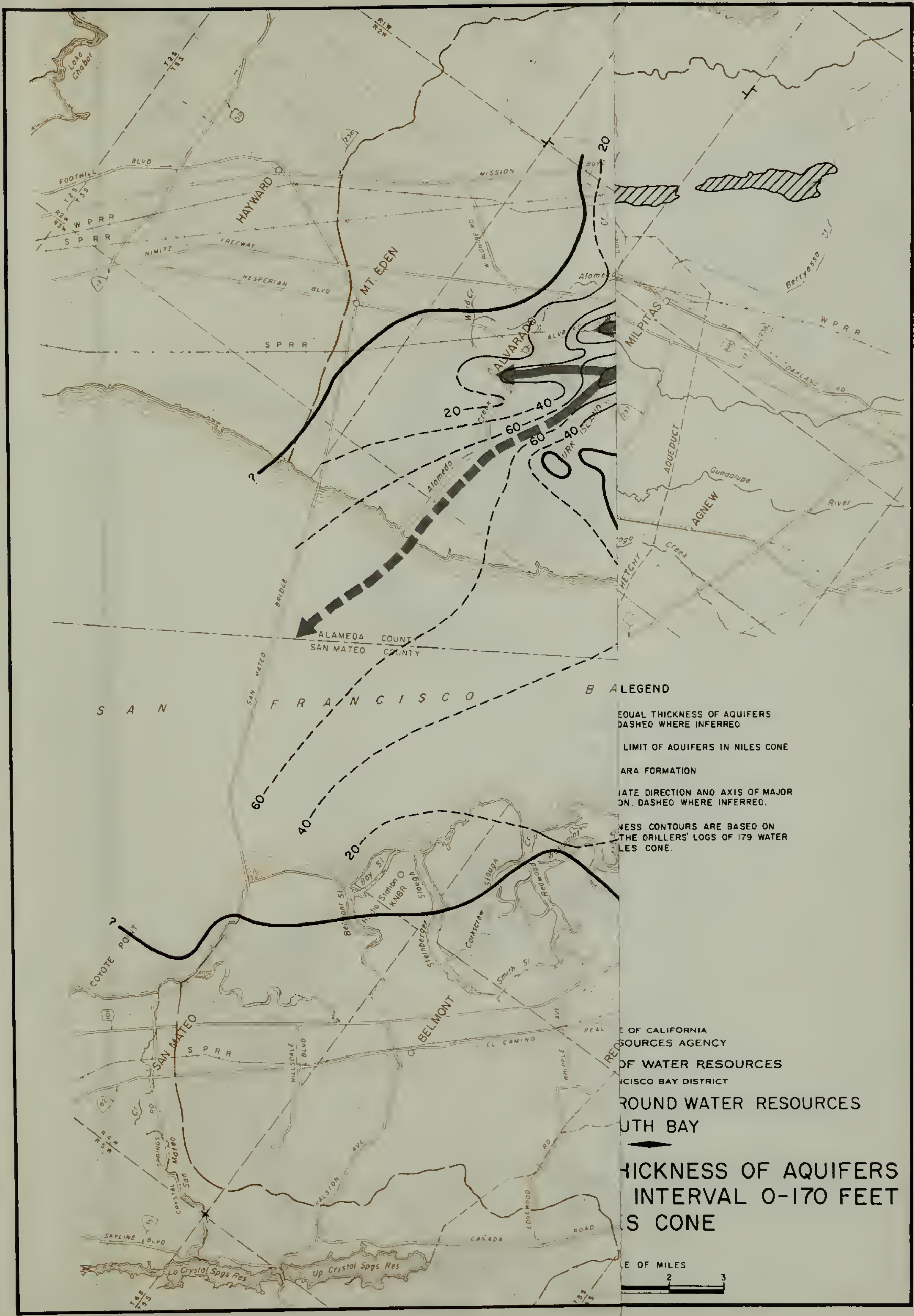
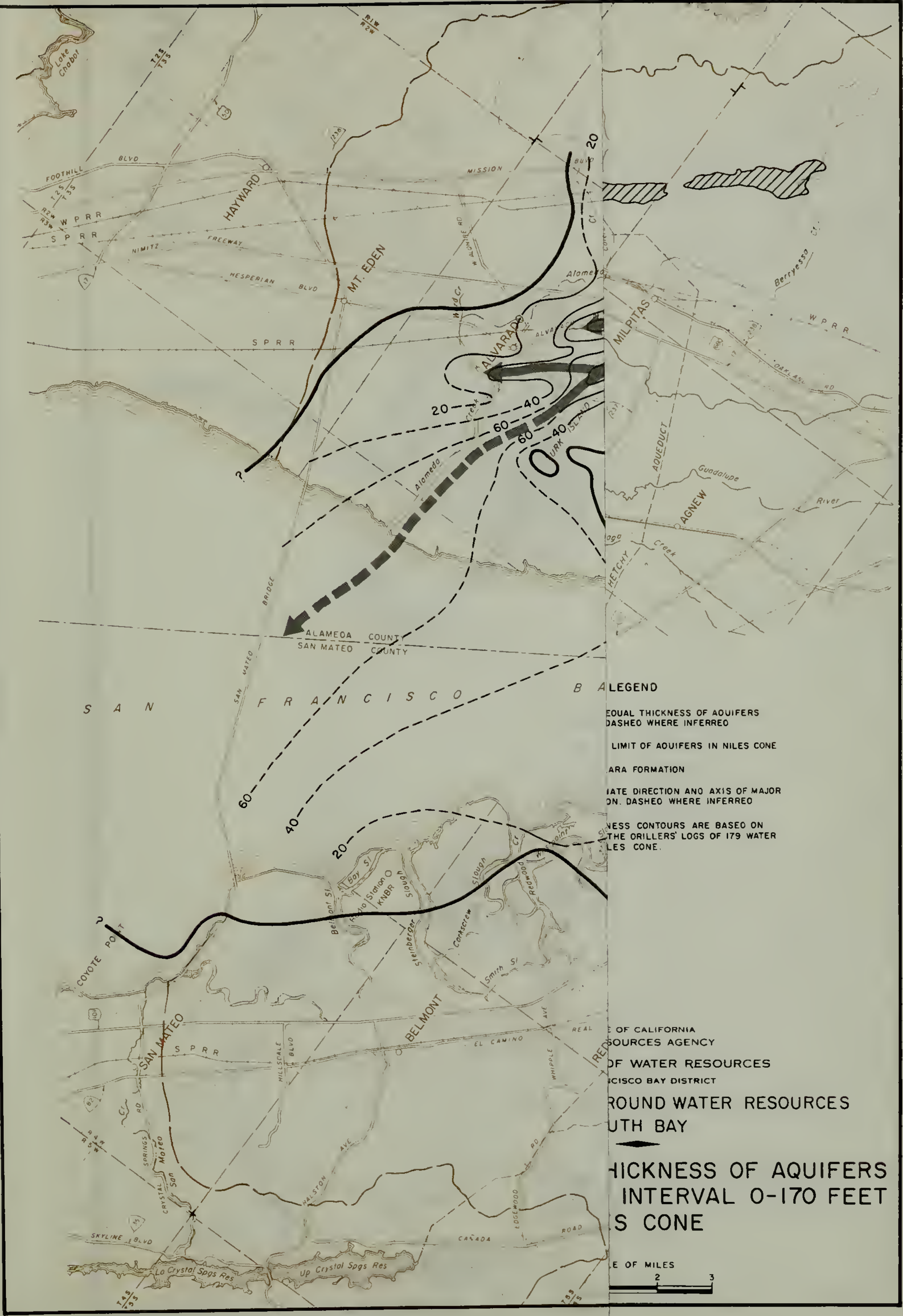
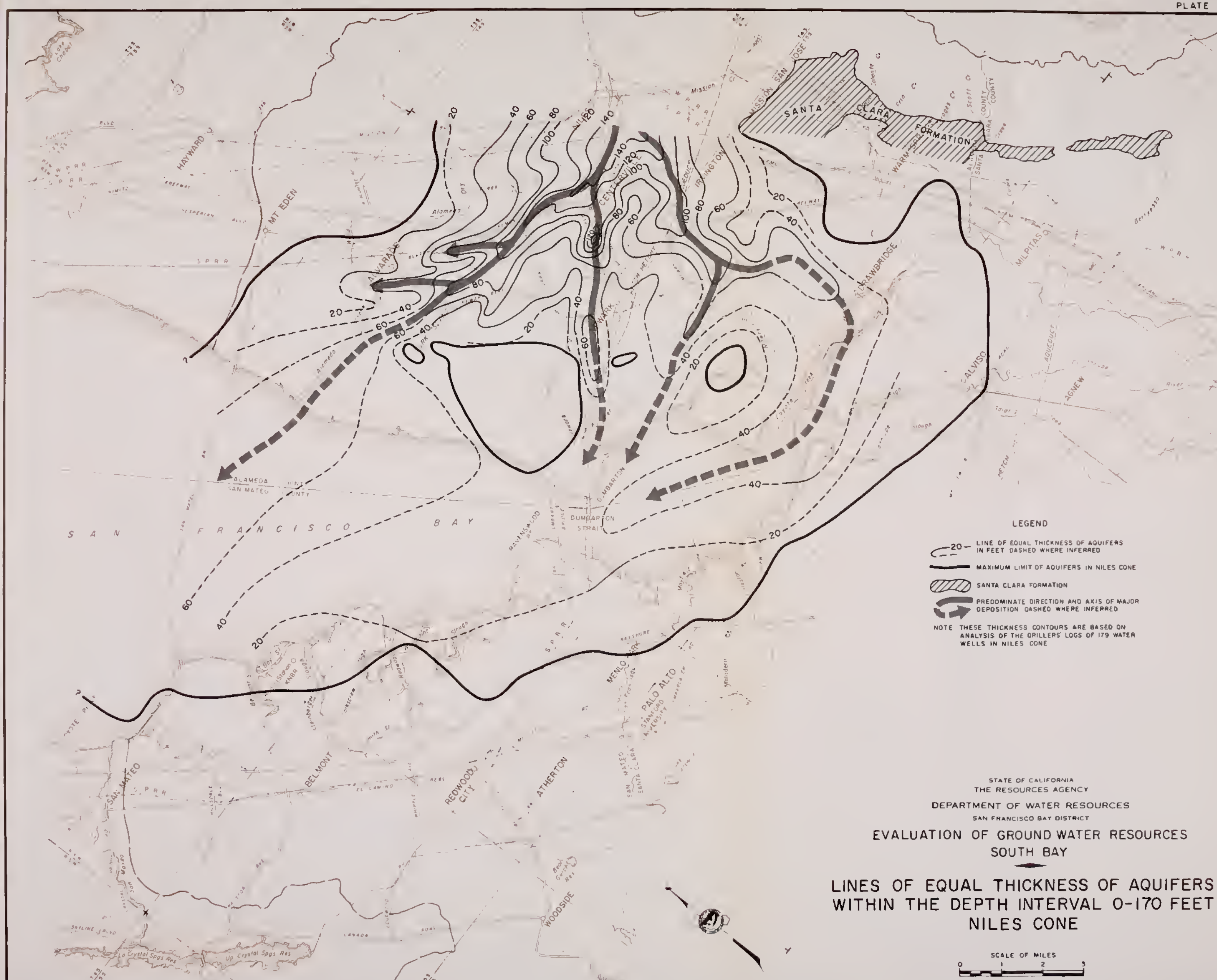
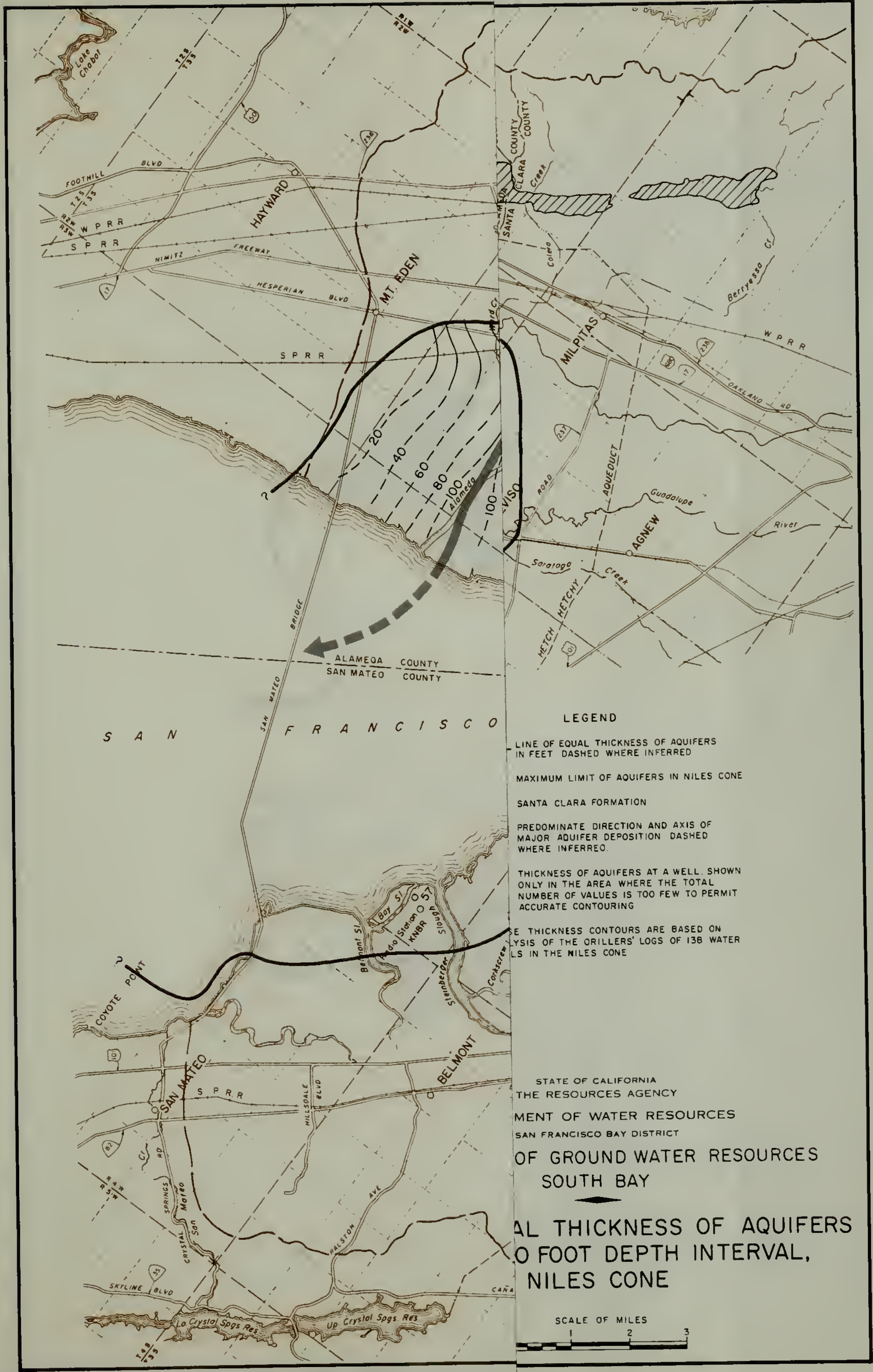

LEGEND
EQUAL THICKNESS OF AQUIFERS
DASHED WHERE INFERRED
LIMIT OF AQUIFERS IN NILES CONE
ARA FORMATION
IATE DIRECTION AND AXIS OF MAJOR
ON. DASHED WHERE INFERRED.
NESS CONTOURS ARE BASED ON
THE DRILLERS' LOGS OF 179 WATER
LES CONE.
E OF CALIFORNIA
SOURCES AGENCY
OF WATER RESOURCES
NCISCO BAY DISTRICT
ROUND WATER RESOURCES
UTH BAY
HICKNESS OF AQUIFERS
INTERVAL 0-170 FEET
S CONE
E OF MILES
2
3
HAYWARD
MT. EDEN
ALVARADO
MILPITAS
AGNEW
BELMONT
SAN MATEO
COYOTE POINT
ALAMEDA COUNTY
SAN MATEO COUNTY
S A N F R A N C I S C O B A
SAN MATEO BRIDGE
Lake Chabot
FOOTHILL BLVD
MISSION BLVD
W P R R
S P R R
NIMITZ FREEWAY
HESPERIAN BLVD
Alameda Creek
Guadalupe River
Berryessa Cr
OAKLAND RD
AQUEDUCT
HETCHY
Coyote Creek
Belmont Sl
Radio Station KNBR
Steinberger Slough
Corkscrew Slough
Redwood Cr
Smith Sl
EL CAMINO REAL
HILLSDALE BLVD
RALSTON AVE
CAÑADA ROAD
SKYLINE BLVD
Lo Crystal Spgs Res
Up Crystal Spgs Res
20
40
60
?

PLATE 12


LEGEND
EQUAL THICKNESS OF AQUIFERS
DASHED WHERE INFERRED
LIMIT OF AQUIFERS IN NILES CONE
ARA FORMATION
IATE DIRECTION AND AXIS OF MAJOR
ON. DASHED WHERE INFERRED
NESS CONTOURS ARE BASED ON
THE DRILLERS' LOGS OF 179 WATER
LES CONE.
E OF CALIFORNIA
SOURCES AGENCY
OF WATER RESOURCES
ICISCO BAY DISTRICT
ROUND WATER RESOURCES
UTH BAY
HICKNESS OF AQUIFERS
INTERVAL 0-170 FEET
S CONE
E OF MILES
2
3
Lake Chabot
HAYWARD
MT. EDEN
ALVARADO
MILPITAS
AGNEW
FOOTHILL BLVD
MISSION BLVD
W P R R
S P R R
NIMITZ FREEWAY
HESPERIAN BLVD
Alameda Creek
Berryessa Cr.
OAKLAND RD
Guadalupe River
AQUEDUCT
HETCHY
ALAMEDA COUNTY
SAN MATEO COUNTY
SAN MATEO BRIDGE
S A N F R A N C I S C O B A
20
40
60
COYOTE POINT
SAN MATEO
BELMONT
EL CAMINO REAL
HILLSDALE BLVD
Belmont Sl
Radio Station KNBR
Steinberger Slough
Corkscrew Slough
Smith Sl
Redwood Cr
RALSTON AVE
WHIPPLE AVE
EDGEWOOD RD
CAÑADA ROAD
SKYLINE BLVD
CRYSTAL SPRINGS RD
Lo Crystal Spgs Res
Up Crystal Spgs Res
San Mateo Cr
T 2 S
T 3 S
T 4 S
T 5 S
R 2 W
R 3 W
R 4 W
R 5 W


LEGEND
LINE OF EQUAL THICKNESS OF AQUIFERS IN FEET DASHED WHERE INFERRED
MAXIMUM LIMIT OF AQUIFERS IN NILES CONE
SANTA CLARA FORMATION
PREDOMINATE DIRECTION AND AXIS OF MAJOR DEPOSITION DASHED WHERE INFERRED
NOTE THESE THICKNESS CONTOURS ARE BASED ON ANALYSIS OF THE DRILLERS' LOGS OF 179 WATER WELLS IN NILES CONE
SANTA CLARA FORMATION
SAN FRANCISCO BAY
DUMBARTON STRAIT
ALAMEDA COUNTY
SAN MATEO COUNTY
HAYWARD
MT EDEN
ALVARADO
NILES
CENTERVILLE
IRVINGTON
MISSION SAN JOSE
WARM SPRINGS
MILPITAS
ALVISO
AGNEW
MENLO PARK
PALO ALTO
STANFORD UNIVERSITY
ATHERTON
REDWOOD CITY
BELMONT
SAN MATEO
WOODSIDE
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER RESOURCES
SOUTH BAY
LINES OF EQUAL THICKNESS OF AQUIFERS WITHIN THE DEPTH INTERVAL 0-170 FEET
NILES CONE
SCALE OF MILES
0 1 2 3



LEGEND

LINE OF EQUAL THICKNESS OF AQUIFERS IN FEET DASHED WHERE INFERRED

MAXIMUM LIMIT OF AQUIFERS IN NILES CONE

SANTA CLARA FORMATION

PREDOMINATE DIRECTION AND AXIS OF MAJOR AQUIFER DEPOSITION DASHED WHERE INFERRED.

THICKNESS OF AQUIFERS AT A WELL. SHOWN ONLY IN THE AREA WHERE THE TOTAL NUMBER OF VALUES IS TOO FEW TO PERMIT ACCURATE CONTOURING

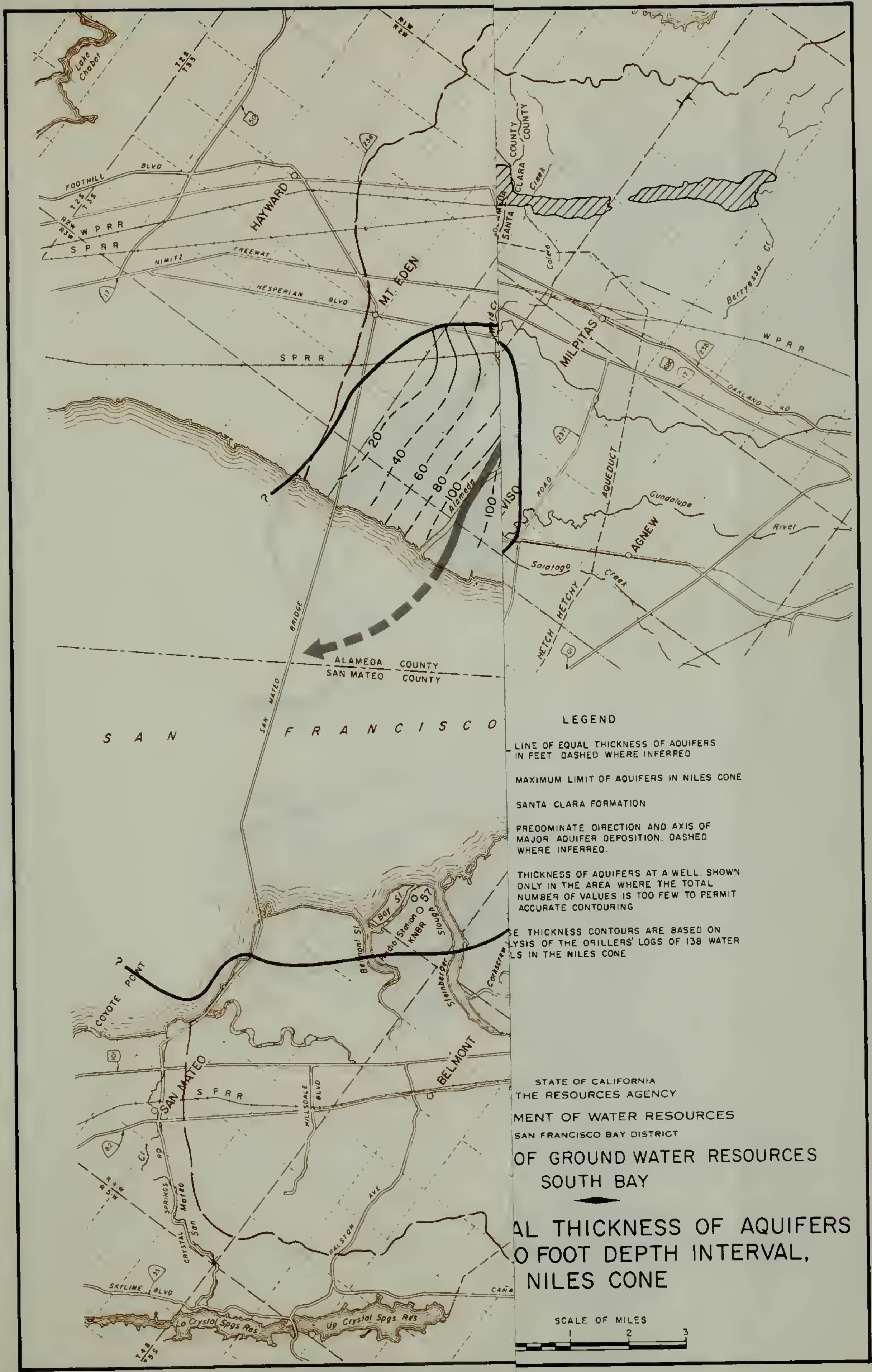
...E THICKNESS CONTOURS ARE BASED ON ...LYSIS OF THE DRILLERS' LOGS OF 138 WATER ...LS IN THE NILES CONE

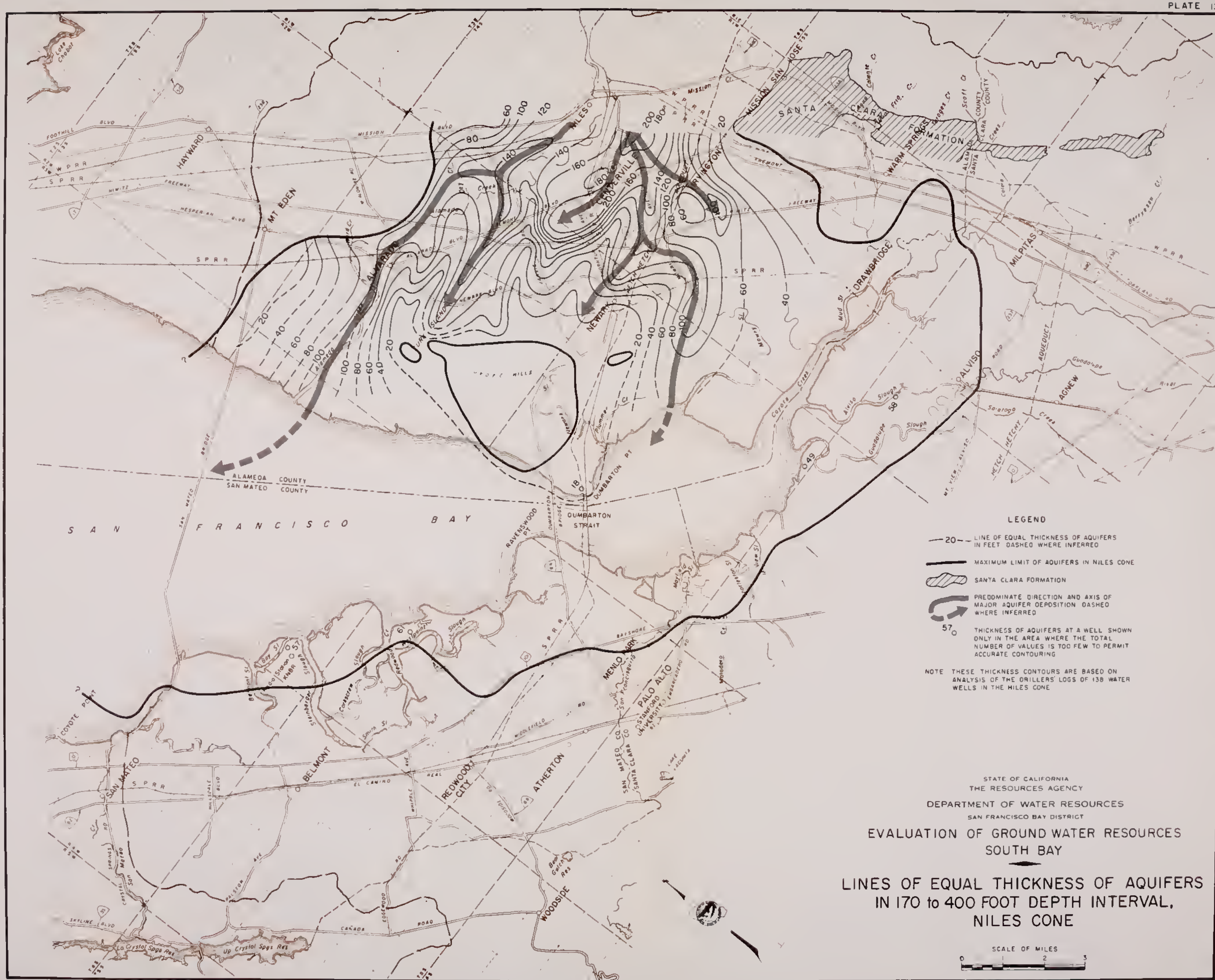
STATE OF CALIFORNIA
THE RESOURCES AGENCY
...MENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT

...OF GROUND WATER RESOURCES
SOUTH BAY

...AL THICKNESS OF AQUIFERS
...0 FOOT DEPTH INTERVAL,
NILES CONE

SCALE OF MILES
1 2 3

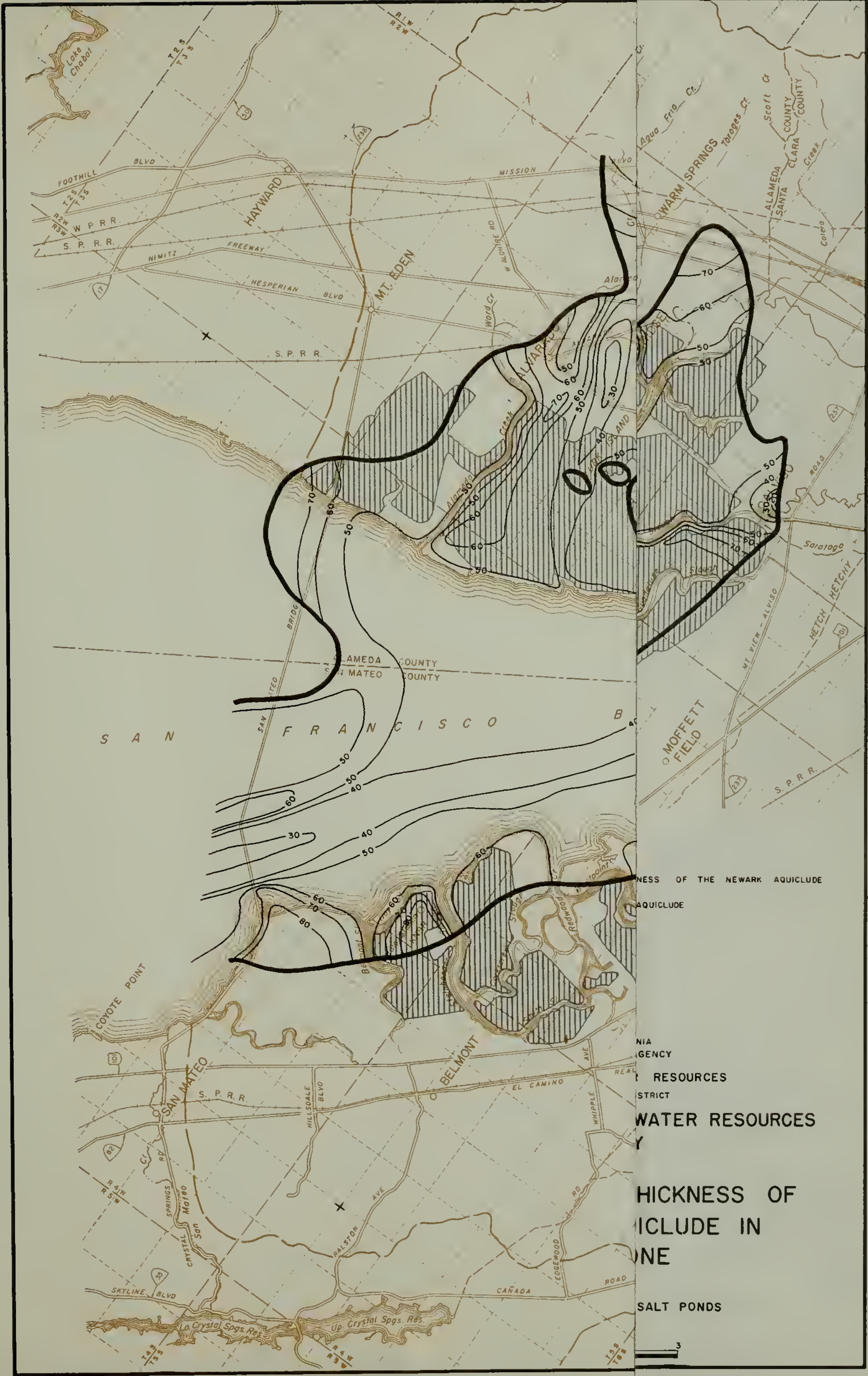

LEGEND
LINE OF EQUAL THICKNESS OF AQUIFERS IN FEET DASHED WHERE INFERRED
MAXIMUM LIMIT OF AQUIFERS IN NILES CONE
SANTA CLARA FORMATION
PREDOMINATE DIRECTION AND AXIS OF MAJOR AQUIFER DEPOSITION. DASHED WHERE INFERRED.
THICKNESS OF AQUIFERS AT A WELL. SHOWN ONLY IN THE AREA WHERE THE TOTAL NUMBER OF VALUES IS TOO FEW TO PERMIT ACCURATE CONTOURING
E THICKNESS CONTOURS ARE BASED ON
YSIS OF THE DRILLERS' LOGS OF 138 WATER
LS IN THE NILES CONE
STATE OF CALIFORNIA
THE RESOURCES AGENCY
MENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT
OF GROUND WATER RESOURCES
SOUTH BAY
AL THICKNESS OF AQUIFERS
O FOOT DEPTH INTERVAL,
NILES CONE
SCALE OF MILES
1
2
3
HAYWARD
MT. EDEN
MILPITAS
AGNEW
ALVISO
SAN MATEO
BELMONT
COYOTE POINT
SAN FRANCISCO
ALAMEDA COUNTY
SAN MATEO COUNTY
SANTA CLARA COUNTY
SAN MATEO BRIDGE
Lake Chabot
FOOTHILL BLVD
HESPERIAN BLVD
NIMITZ FREEWAY
W P R R
S P R R
HETCH HETCHY AQUEDUCT
Guadalupe River
Saratoga Creek
Coyote Creek
Berryessa Cr
Alameda
OAKLAND
SKYLINE BLVD
HILLSDALE BLVD
RALSTON AVE
CRYSTAL SPRINGS RD
La Crystal Spgs Res
Up Crystal Spgs Res
Belmont Sl
Bay Sl
Radio Station KNBR
Steinberger Slough
Corkscrew
20
40
60
80
100
100
57



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES
SOUTH BAY

LINES OF EQUAL THICKNESS OF AQUIFERS IN 170 to 400 FOOT DEPTH INTERVAL, NILES CONE


Lake Chabot
HAYWARD
MT. EDEN
FOOTHILL BLVD
MISSION BLVD
W P R R
S. P. R. R.
NIMITZ FREEWAY
HESPERIAN BLVD
WARM SPRINGS
Agua Fria Cr.
ALAMEDA COUNTY
SANTA CLARA COUNTY
ALVARADO
ALAMEDA COUNTY
SAN MATEO COUNTY
SAN FRANCISCO BAY
MOFFETT FIELD
COYOTE POINT
SAN MATEO
BELMONT
EL CAMINO REAL
HILLSDALE BLVD
SKYLINE BLVD
CAÑADA ROAD
Lo. Crystal Spgs. Res.
Up. Crystal Spgs. Res.
Saratoga
HETCH HETCHY
NESS OF THE NEWARK AQUICLUDE
AQUICLUDE
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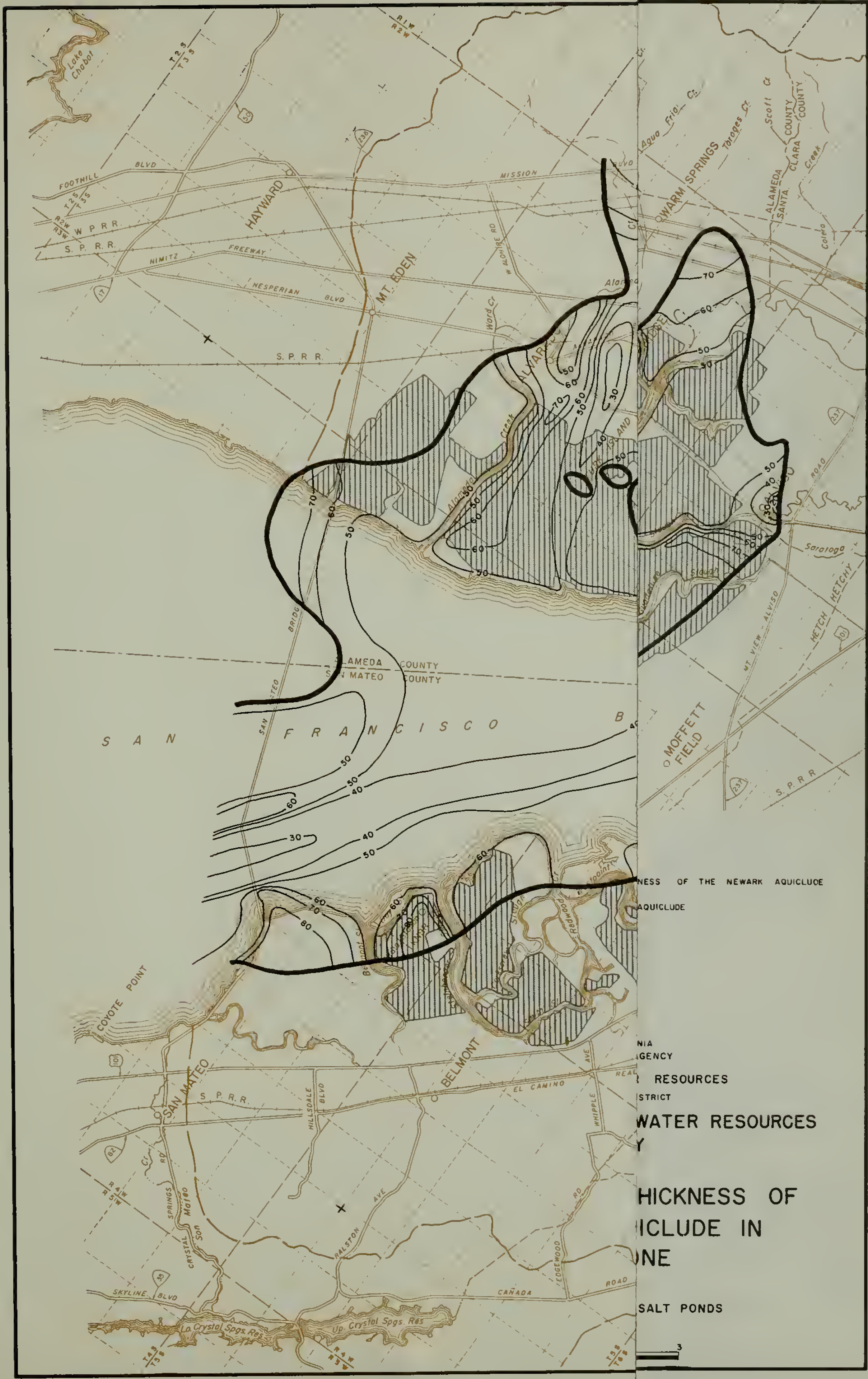
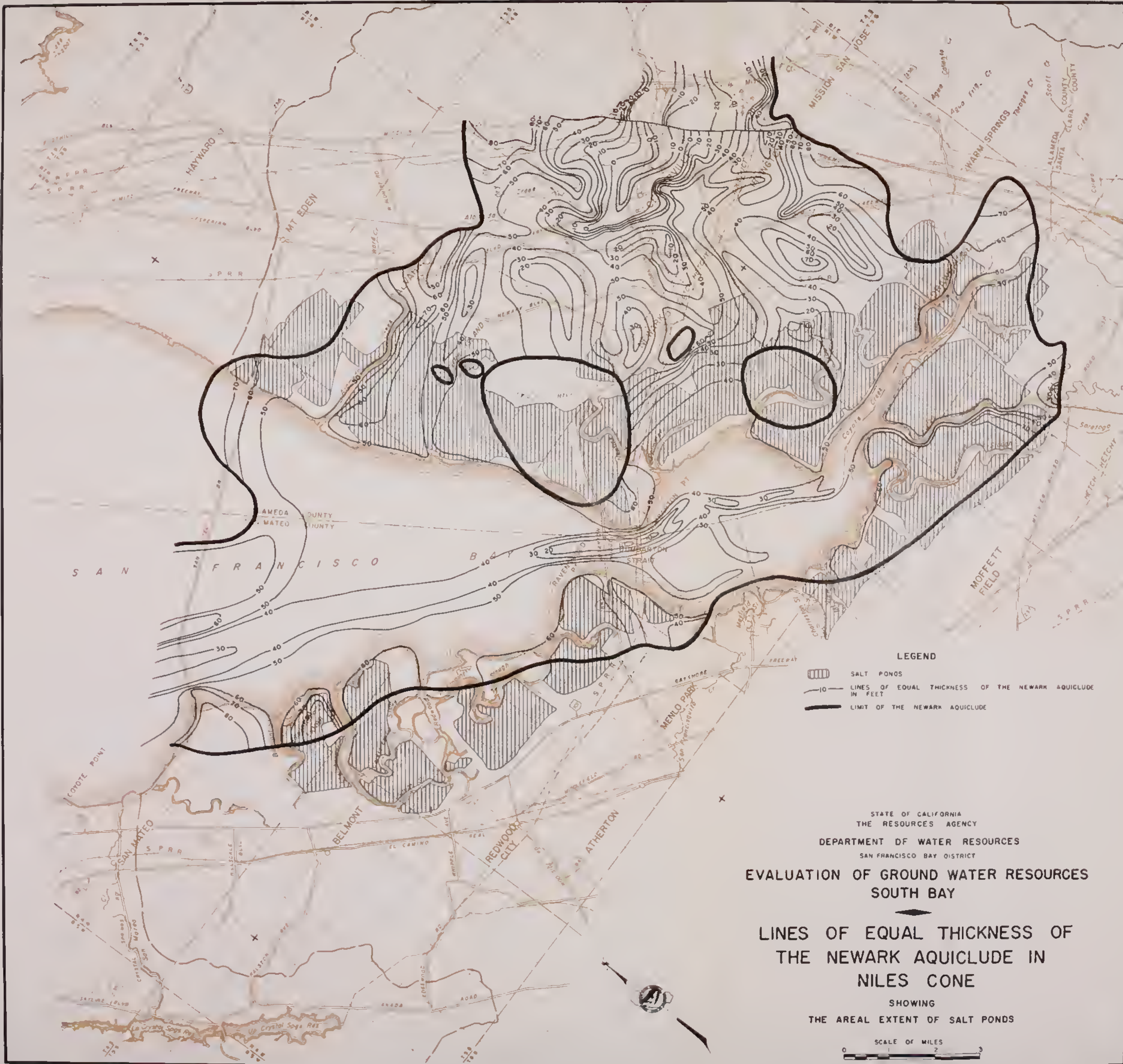
R RESOURCES
STRICT
WATER RESOURCES
Y
HICKNESS OF
ICLUDE IN
ONE
SALT PONDS


Lake Chabot
HAYWARD
MT. EDEN
FOOTHILL BLVD
MISSION BLVD
W.P.R.R.
S.P.R.R.
NIMITZ FREEWAY
HESPERIAN BLVD
WARM SPRINGS
ALAMEDA COUNTY
SANTA CLARA COUNTY
ALVARADO
ALAMEDA COUNTY
SAN MATEO COUNTY
SAN FRANCISCO B
MOFFETT FIELD
COYOTE POINT
SAN MATEO
BELMONT
EL CAMINO REAL
HILLSDALE BLVD
SKYLINE BLVD
CAÑADA ROAD
Lo. Crystal Spgs. Res.
Up. Crystal Spgs. Res.
HETCH HETCHY
MT. VIEW - ALVISO ROAD
Saratoga
NESS OF THE NEWARK AQUICLUDE
AQUICLUDE
NIA
GENCY
R RESOURCES
ISTRICT
WATER RESOURCES
Y
HICKNESS OF
ICLUDE IN
NE
SALT PONDS



LEGEND
SALT PONDS
LINES OF EQUAL THICKNESS OF THE NEWARK AQUICLUDE IN FEET
LIMIT OF THE NEWARK AQUICLUDE
SAN FRANCISCO BAY
DUMBARTON STRAIT
ALAMEDA COUNTY
SAN MATEO COUNTY
SANTA CLARA COUNTY
HAYWARD
MT EDEN
MISSION SAN JOSE
WARM SPRINGS
MOFFETT FIELD
MENLO PARK
ATHERTON
REDWOOD CITY
BELMONT
SAN MATEO
COYOTE POINT
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER RESOURCES
SOUTH BAY
LINES OF EQUAL THICKNESS OF THE NEWARK AQUICLUDE IN NILES CONE
SHOWING
THE AREAL EXTENT OF SALT PONDS
SCALE OF MILES
0
1
2
3